(12)

Technical Report 508

AD-A136605

THE HUMAN FACTORS OF GRAPHIC INTERACTION: TASKS AND TECHNIQUES

James D. Foley and Peggy Chan
George Washington University

and

Victor L. Wallace
University of Kansas

HUMAN FACTORS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

December 1980

U. S. ARMY RESEARCH INSTITUTE

FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

JOSEPH ZEIDNER
Technical Director

L. NEALE COSBY
Colonel, IN
Commander

Research accomplished under contract
for the Department of the Army

The George Washington University/Dept. of Electrical Engineering and
Computer Science

NOTICES

<u>DISTRIBUTION</u>: Primary distribution of this report has been made by ARI. Please address correspondence concerning distribution of reports to: U.S. Army Research Institute for the Behavioral and Social Sciences, ATTN: PERI-TST, 5001 Eisenhower Avenue, Alexandria, Virginia 22333.

<u>FINAL DISPOSITION</u>: This report may be destroyed when it is no longer needed. Please do not return it to the U.S. Army Research Institute for the Behavioral and Social Sciences.

<u>NOTE</u>: The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report 508	2. GOVT ACCESSION NO. AD-A136605	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE HUMAN FACTORS OF GRAPHIC INTERACTION: TASKS AND TECHNIQUES		5. TYPE OF REPORT & PERIOD COVERED Jan '79 - Dec '80 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James D. Foley Victor L. Wallace - University of Kansas Peggy Chan		8. CONTRACT OR GRANT NUMBER(s) MDA-903-79-G-01
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dept. of EE & CS The George Washington University Washington, D.C. 20052		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q161102B74F
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue Alexandria, VA 22333		12. REPORT DATE December 1980 13. NUMBER OF PAGES 153
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This research was technically monitored by Franklin L. Moses of the Human Factors Technical Area of ARI.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Interactive Computer Graphics
Graphic Interaction Techniques
Human Factors of Graphic Interaction
Graphics Interaction Experiments
Graphic Positioning Techniques
Graphic Orienting Techniques
Graphic Quantifying Techniques
Graphic Selection Techniques
Graphic Text Entry Techniques

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Choices among techniques and hardware devices which allow users to interact with a computer-generated environment through computer graphics are described and discussed. These interaction techniques provide communication with the system through commands and information associated with the commands. Each technique has some purpose, such as to specify the command, designate a position, or select a displayed object, and each is implemented with some device, such as a tablet, joystick, keyboard,

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

light pen, track ball, or potentiometer. Important human factors issues, experiences, and experiments bearing on the selection of one technique or device in favor of another are presented.

A way to precisely describe an interaction technique, the interaction technique diagram, is introduced. Nine relevant experiments are abstracted and critiqued, and their experimental procedures are described using the technique diagrams.

Technical Report 508

THE HUMAN FACTORS OF GRAPHIC INTERACTION: TASKS AND TECHNIQUES

James D. Foley and Peggy Chan
George Washington University

and

Victor L. Wallace
University of Kansas

Submitted by:
Stanley M. Halpin, Acting Chief
HUMAN FACTORS TECHNICAL AREA

Approved by:
Edgar M. Johnson, Director
ORGANIZATIONS AND SYSTEMS
RESEARCH LABORATORY

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

December 1980

Army Project Number
2Q161102B74F

Personnel Performance and Training (Basic Research)

ARI Research Reports and Technical Reports are intended for sponsors of R&D tasks and for other research and military agencies. Any findings ready for implementation at the time of publication are presented in the last part of the Brief. Upon completion of a major phase of the task, formal recommendations for official action normally are conveyed to appropriate military agencies by briefing or Disposition Form.

FOREWORD

The Human Factors Technical Area of the Army Research Institute conducts research directed toward the improvement of user-computer systems designed to acquire, transmit, process, disseminate, and utilize information from an increasingly complex battlefield. The research is focused on the interface problems and interactions within battlefield automated systems, emphasizing such areas as tactical symbology, user-oriented systems, information management, computer support to staff operations and procedures, and integration and utilization of the sensor systems.

One area of special research interest is the design of effective and efficient on-line interaction between the operator/user and the computer. Research is directed toward enhancing computer-based displays and associated features of tactical data input, retrieval, and analysis. This publication explores interactive graphic techniques which allow the user to directly interact with the display. This effort is one element of a program to explore improved technology for user and computer communication and provides the technological base necessary for effective design of the interface.

Research in the area of concepts for man-computer synergism is conducted as an in-house effort augmented by contracts with organizations selected for their specialized capabilities and facilities. The efforts are responsive to general requirements of Army Project 2Q162717A790 and to special requirements of the U.S. Army Combined Arms Combat Development Activity, Fort Leavenworth, Kansas. This specific effort was conducted under Army Project 2Q161102B74F as basic research responding to the above requirements.

Joseph Zeidner

JOSEPH ZEIDNER
Technical Director

Acknowledgements

The authors are grateful to a large number of people for their advice, information, and sources. We are particularly grateful to Terry Jennings, student assistant at the University of Kansas, and John L. Burch, consultant on this project and president of Ergosyst Associates, Inc. They both worked with us throughout the project, wrote portions of the draft, engaged in many fruitful discussions and critiques, and contributed freely with their ideas and knowledge. We are indebted to Dr. Franklin Moses of The U. S. Army Research Institute for the Behavioral and Social Sciences (ARI), for his support, encouragement, expert criticism, helpfulness, and patience.

BRIEF

Requirement:

To provide a means for designers to choose appropriate user-computer interactive devices and techniques.

Procedure:

Basic and applied data were collected, analyzed and structured about human factors issues, experiences, and experiments to guide understanding of how to select one interactive technique or device over another.

Findings:

A structure is proposed for organizing material about interactive techniques and the <u>interactive technique diagram</u> is introduced to describe them. A multitude of interactive techniques can provide communication with a computer system although some techniques are better for one purpose than for another; for example, specifying a command or designating a position may be effectively implemented with a particular device such as a tablet, joystick, keyboard, light pen, track ball, or potentiometer. Specific experiments are abstracted and critiqued, and their experimental procedures are described using the technique diagrams.

Utilization of Findings:

Interactive techniques and devices are critical parts of the user-computer interface. The costs of poorly designed interfaces can include degraded user productivity, user frustration, increased training costs, etc. Task requirements serve to limit the set of techniques which can be considered for a particular application. The interaction technique diagram suggested in the paper provides a basis for designers to select appropriate equipment for increased functional effectiveness of the user-machine interface.

TABLE OF CONTENTS

APPENDICES

TABLES AND FIGURES

1. Introduction

The promise of interactive graphics is to provide a user with a medium for communication with a computer which is at once benign, responsive and graphic. We should expect it to be benign and responsive in the same sense a trusted servant is expected to be. We should expect it to be graphic with the clarity and richness of communication that only graphic communication presents. When a person uses an interactive graphics system to do real work, he wants the system to virtually disappear from his consciousness so that only his work and its ramifications have a claim on his energy.

This promise is frequently not fulfilled. Designers of graphics systems, software and hardware, often lack the intuition, knowledge, and experience necessary to truly "engineer" the forms of the dialog between man and computer to best advantage. The fault lies partly with current literature, and partly with the state of our knowledge of the methodology and information structures by which such designers can be successful. Good designs are usually the result of a diligent, but essentially creative, enterprise.

It is our thesis that, in the development of methodology and structures to ensure that good design of interaction interfaces is made easier and more reliably sound, one of the first places to start is in the process by which the designer selects the devices and techniques which the user uses to achieve his elementary tasks. The purpose of this report is to provide some systematic structure for this process. The purpose of our work is to aid the designer in making this selection.

There are a multitude of interaction techniques, many of which are described in later sections. Each has a specific purpose, such as to specify a command, designate a position, or select a displayed object, and each is implemented with some device, such as a tablet, joystick, keyboard, light pen, track ball, or potentiometer. Typical techniques which many readers may be familiar with are: are selecting a command from a menu using a light pen, specifying a position using a tablet or joystick along with cursor feedback on the screen, typing a numeric value on a keyboard, or designating a displayed object with a light pen.

Interaction techniques and devices are important parts of the user-computer interface. We all recognize, from our own experiences with interactive computing (which need not have been with interactive graphics), the costs of poorly-designed interfaces. Coming in many forms, the costs can include degraded user productivity, user frustration, increased training costs, the need to redesign and re-implement the user interface, etc. Specific experiments, discussed later in this paper, confirm that the costs are real. How can we avoid these costs? Where can we turn for guidance? There are three basic sources of information:

1) Experience-based guidelines,

2) Experiments with interaction techniques, and

3) The human-factors literature, especially that dealing with equipment design.

Over the past ten years much lore has developed concerning what makes interactive graphics systems easy (or hard) to use, and concerning the pros and cons of various interaction devices and techniques. Much of this lore has not found its way into the literature. Furthermore, that lore which can be found in the literature is typically scattered amidst application descriptions. Only a few writers [BENN77, BRIT77, CHER76, ENGE75, FOLE74, HANS71, WALL77] have attempted to summarize in a structured way either their design philosophy, or their accumulated knowledge and experience. These papers represent one source of guidance.

A modest collection of experiments [CARD78, CONR66, EARL65, ENGL67, FIEL78, GALL66, GOOD75, IRVI76, MEHR72, MORR68] comparing different interaction techniques have been undertaken, starting in the late 1960's. Some of the experiments have been performed by computer scientists, others by human factors specialists, and still others collaboratively by multi-disciplinary teams. The results of these experiments are often useful, but generalizing beyond the specific circumstances of the experiment is difficult. Ramsey and Atwood [RAMS79], as part of a larger effort, present a (10-page) review and discussion of the results of most of these experiements. Appendix A presents a method for more precisely describing the experiments, and appendix B contains summaries and critiques of these experiments.

The final and most promising source of possible guidance is the human factors literature. There is no single, coherent human factors literature as such because of the diversity of problem areas and research disciplines that are involved in human factors work. Thus we find a diverse mixture of ad hoc experiments, evaluations, and lore together with important treatises on methodology, all packaged into a handfull of books and professional journals and a very large number of hard-to-find technical reports. In general the human factors literature concentrates on human capabilities and limitations, and is clustered under the following topics: information presentation (visual and auditory), human control of systems, man as a system component (e.g., "man-in-the-loop" models), workspace design, and methods for observing, analyzing and measuring human performance.

The field of human factors engineering (or ergonomics) is better defined in terms of its objectives than its researcher and practitioner constituencies, since it is multidisciplinary as well as interdisciplinary in makeup, with perhaps its heaviest concentrations in the behavioral and biological sciences. At one extreme it fades into environmental psychology and at the other it merges with physiology. The common objective of all human factors work is simply stated: to

achieve functional effectiveness in whatever physical equipment or facilities people use, through appropriate design.

Unfortunately, the most common textbook in this extremely diverse field, [MCCO76], while providing an excellent general survey and claiming to illustrate how human factors can influence the design process, succeeds only in describing the relevant research, not how it can be applied. Also, aside from some useful tables on control devices [CHAP72], little practical guidance is offered to designers and virtually none to the designers of interactive graphics devices or systems.

The two "classics" on equipment design [WOOD64 and VANC72] are of greater practical value, the former as a repository of accumulated lore and the latter as a compendium of studies, surveys, and experiments; [CHAP65] and [FITT54] might also be consulted. These works, however, all predate the advent of interactive computer systems and are mostly concerned with the human interface to machines that are used to control other physical machinery or process variables. Thus they provide only a general backdrop of ideas for designers of complex, interactive, information processing equipment. More recent work has begun to deal with the operation of computer-controlled equipment [SHER74] but this has tended to be more concerned (justifiably) with the development of an adequate theory than with heuristics for designers.

The human factors fields have always faced severe methodological challenges both in collecting trustworthy data from observations of people actually using machines, and in conducting human experimentation that can be reliably applied to the design of man-machine systems. [CHAP59] remains the only source of guidance on these questions which are certainly no less important in the case of information processing machines than, say, of cockpits or control towers. Yet, although the graphics system designer badly needs to sharpen his observational and experimental technique in order to improve the reliability of design decisions affecting users, the methods of cognitive ergonomics, which are so critical to interactive information systems, are not discussed at all in Chapanis' work which even predates the field of theoretical or cognitive psychology.

Much attention has also been devoted to the chronic problem of integrating human factors awareness into the early stages of the design process where it can have the greatest benefit [MEIS71 and MEIS76]. Although recent work of this type has focused on the use of behavioral data as a foundation for system design [MEIS76], it has concentrated on very large-scale, multi-person (crew) systems and the work is difficult to generalize to other types of systems.

Recently, interest in white-collar ergonomics, particularly in Europe, has generated a lot of work in the human factors relevant to the design of alphanumeric video-display terminals (VDT's) and their various workplace environments. [CAKI80] summarizes this work and offers recommendations for the elimination of such ailments as eyestrain and backache on the part of VDT operators, much of which can certainly apply to graphics systems whose operators often spend endless hours leaning uncomfortably forward in their seats to work at their consoles.

However, this very good, but traditional human engineering study says nothing about how to design interactive techniques that might foster a more intimate coupling of man and machine. It, like the bulk of the human factors literature, is aimed at eliminating hazards and alleviating hinderances rather than at directing system design in a positive sense.

The difficulties with all these different sources of guidance are that they are hard to locate, are usually couched in disciplinary jargon, and use little consistent terminology. Consequently, the designer of an interactive system must, to a large degree, rely primarily on personal experiences, and on those of colleagues despite the existence of many potentially useful materials. Instead of standing on their professional forebears' shoulders, designers seem destined to stand only on their forebears' toes.

Our intent in this paper is to integrate within a unified and logical structure a significant and useful body of the experiential and experimental conclusions drawn from these sources.

1.1. Scope.

The designer of an interactive graphics system must define everything about the user-computer interface. This ranges from the concepts with which the user must deal with down to the finer details of screen formats, interaction techniques, and device characteristics. In this present section we briefly describe the overall design process to show how the issue of interaction technique fits into the whole.

Many writers [BRIT77, WALL77, FOLE80, NEWM79, MORA78, DUNN80] have suggested a top-down design approach. The first step in the process is to understand the application area and prospective users. This can be done in part by studying the way the application is currently treated. As Hornbuckle [HORN67] says, "observing what man does normally during his creative efforts can provide a starting point for the ... designer. In particular, a mathematician does not manipulate equations at a typewriter, nor does a circuit designer prefer a keypunch." Hansen [HANS71] is even more succinct: his advice is "Know the User." Watch him, study him, interact with him, learn to understand how he thinks, and why he does what he does.

The process of understanding the application is often called the requirements definition process. It results in a set of functional requirements, or capabilities, which are to be made available through the user-computer interface. This process can also provide insights into how the capabilities of the system might best be presented to the user. Finally, the analysis identifies the types of user for which the system is to be designed.

The results of a requirements definition are eventually used as the basis for defining the languages of interaction between computer and user. We view the user-computer interface as composed of two languages:

with one language the user communicates to the computer; with the other the computer communicates to the user. Because our focus is on interaction techniques for input (user to computer communication), we will discuss only the input language. Defining an input language is a top-down process, starting with the user's conceptual model, then the command structure, the syntax, and finally the assignment of physical devices and activities. Interaction techniqes, which are the focus of this report, are directly involved only in the latter process.

As a first step, we define the fundamental conceptual model with which the user must deal. The conceptual model, sometimes called high-level semantics, embodies the key components from which the detailed semantics (i.e., commands) are developed. If we were defining a text editor, possible conceptual models are the line number-oriented editor or the screen editor.

The second step, defining the detailed semantics of a language, follows from the conceptual model and the functional requirements. Semantics is the set of meanings conveyed by the language, and includes the modifiers (adjectives, adverbs, prepositions) of the language. The commands are the semantics of the input language, while the collection of information available for display to the user represents the semantics of the output language.

The language syntax, formed as the third step, defines how the units (words) which convey semantics are assembled into a complete sentence which instructs the computer to perform a certain task. Even for simple operations, considerable syntactic variety is possible. Consider, for example, a "move entity" command for a drafting program. Six possible syntaxes are:

<move command> ::=	<move>	<entity>	<position>
	<move>	<position>	<entity>
	<entity>	<move>	<position>
	<entity>	<position>	<move>
	<position>	<move>	<entity>
	<position>	<entity>	<move>

Each of these three tokens, <move>, <entity>, and <position> is a primitive nonterminal symbol in the syntax of the input language. By "primitive nonterminal", we mean a symbol which would be replaced by one or more terminal symbols were an additional production rule applied.

At the fourth step, the lexical design, these primitive nonterminals are bound to hardware devices. This is exactly where the interaction techniques come in! A technique is a binding of one or more hardware devices to primitive nonterminal symbols in the command language syntax.

We call this lexical level design because of its correspondence to the binding of syntactic tokens to lexemes in the input alphabet. Thus the lexical-level design requires selection of hardware devices and of the interaction techniques with which the devices will be used. The distinction between the syntactic and lexical designs is that the syntactic design stops with the primitive nonterminals, at the point where

further specification would result in binding to devices. That is, the syntactic design is device-independent, while the lexical design is device-dependent. In the example of the move command sequence given above, the token "move" might be bound to hardware devices such as a keyboard, a light pen (using menu selection), or a speech recognizer.

In summary, we have a *four-step* top-down design process for the user interface; the steps being conceptual design, semantic design, syntactic design, and lexical design. Our focus is on the lexical design, in which specific interaction techniques and devices are used.

Because primitive techniques will be strung together syntactically into sentences, and sentences combined into larger structures governed by the underlying semantics of the application, it is impossible to ignore the effect of context upon the selection of a technique. Surely, when deciding whether to carry out a positioning task by using a light pen or a mouse, it makes a difference whether the task immediately preceding or the task immediately following the locating task involved a light pen. The user might well be more productive if there were a continuity of devices across the sequence of tasks, i.e. across the sentence.

The scope of our work does not extend to the physical design of interaction devices. Issues such as key shape, keyboard slant, and light pen diameter are beyond our scope, and are being treated extensively in the literature of traditional human factors. Our basic guideline is that device characteristics which are normally under computer control are considered in our work, while characteristics normally built into the device hardware are not. We take the necessary liberty of assuming that whatever devices may be selected are optimally-designed for their intended use.

1.2. Interaction Tasks

Most commands to an interactive system have several primitive non-terminal symbols. The "move entity" command illustrated in the preceding section has three such symbols: a position, an entity, and the imperative, "move". The entry of each symbol by the user is an interaction task, performed using an interaction technique. Each task can be implemented by many different techniques. The designers of the interactive system must select those interaction techniques which best match both the user's characteristics and the specific requirements of the interaction task, and must also select the appropriate device. In some cases the devices will already be pre-determined, having been selected by the hardware procurers rather than by the user interface designers. This unfortunate situation reduces the number of alternative design decisions to be considered, and may result in a sub-optimum design.

As we will later describe in detail, each task has certain requirements which are dictated by the application and/or user, and each technique has certain properties. For example, a requirement of a

positioning task may be that positions be indicated in 3D, while a property of a positioning technique may be that it works only in 2D. The 2D techniques would therefore not be considered for use.

1.3. Psychological and Physiological Foundations

Interacting with a computer, like all human behavior, involves three types of basic human processes: perception, cognition, and motor activity. The system designer's job is to design interaction techniques in which the work required by these processes--both individually and in combination--is minimized.

The purpose of this section is to briefly mention some of the key concepts from psychology, physiology, and human factors which relate to these processes. Human factors contributes most heavily to the perceptual and motor processes, being concerned as it is with the application of psychological and physiological knowledge to human performance, much as engineering is concerned with the application of physics and mathemathics. The field of cognitive psychology provides insights into our memory and learning processes.

It is beyond our scope to describe the relevant theories and results from each of these areas. The interested reader is referred to the previously mentioned human factors texts, to [LINS77, LACH79, REYN77, NEIS67, UNDER78, and NILS79] (cognitive psychology), and to [KOLE79] (visual perception). [MICH79] may also be of interest. In the following sections we simply indicate some relevant considerations drawn from each of these areas.

1.3.1. The Perceptual Process

Perception is the process whereby unintelligible physical stimuli (generated in this case by the computer) are received by the receptor organs, transmitted to the brain, and are there recognized by a process theorized to be akin to pattern recognition. The dominant stimuli in most cases are visual, although audio stimuli have traditionally been present to some degree (keyboard clicks, disc access arms moving, etc.) and are now commonly used (e.g., tones to catch the user's attention, speech output, etc.) as an adjunct to or replacement of visual stimuli. Also tactile stimuli are present while grasping for interaction devices.

Most interaction techniques start with visual perception: the user locates a menu selection, an entity to be deleted, or the cursor, and recognizes a form or shape. Thus an important consideration is in displaying the information the user needs for the technique so that it can be quickly located. This means using methods such as color-coding, spatial-coding, blinking, brightening, movement, and reverse video to call the user's attention to specific parts of the display.

Of course, if a technique may involve any of the entities being displayed, there is no point in highlighting them all. Often, however, the application is such that subsets of displayed information are most germane only at specific points in time.

Issues of display brightness, line thickness, and character fonts and sizes are also relevant here. For instance, some fonts are more easily read than are others. Spacing is important also, since menu items crammed together are much more difficult to perceive than if they were separated by blank space.

1.3.2. The Cognitive Process

Cognition is the process by which the user assigns meanings to the perceived physical stimuli, and makes decisions based both on those meanings and on the previously accumulated (i.e., learned) information already stored in his mind. This decision-making process involves pattern recognition, that integrative/selective process by which we make sense of the millions of discrete signals received by our brains each second. It is behavior which can be learned and requires less and less conscious attention, the more skilled the performer becomes. Much, perhaps most, cognitive work at the lexical level of interaction is unconscious and virtually instantaneous. However, there is a real and significant cognitive component to every human act.

Reaction times are an important but admittedly gross measure of cognitive work. However, the physiological limits governing perceptual and especially motor processes, which are also included unavoidably in any measurement of reaction times, can mask the time actually devoted to cognition alone when the latter is below a certain threshold.

Human factors engineering traditionally is not concerned with cognition but concentrates instead on designing equipment for efficiency of manipulation approaching physiological limits. Tasks involving interactive computers, however, almost by definition, have non-trivial cognitive components even at this lowest or lexical level. Designers of interaction techniques, therefore, must understand the functions of cognition because that process will sometimes be the rate-determining step of a technique.

Cognition provides insights into ways to structure hierarchical menus, the number of choices to present to a user, the types of words to use in a menu, and ways to abbreviate or name commands. When we "learn" how to use an interaction technique, we acquire and organize information concerning its use. If the information fits into catagories or concepts we already understand, then the learning can proceed rapidly; if not, learning can be slower. Menu symbols or names which are already "known" to the user are easier to deal with than ones which are unknown; a menu of 20 choices may be made easier to comprehend by grouping the choices into several logically related subsets.

1.3.3. The Motor Process

This process comes into play when the user, having received, recognized, and decided how to respond to the stimuli, performs a response in physical actions. This may involve picking up a tablet stylus, moving it to the tablet, and then causing the cursor to move to a particular point on the screen.

The motor process almost always depends on continuous perception and cognition to close the feedback loop. In the cases just described, perception informs the user of the locations of the tablet and stylus, or cursor and target respectively, and cognition continually decides whether or not these locations have converged. In the case of typing a command in response to a prompt, a touch typist would not depend on visual perception of the keys for feedback, but would instead rely on kinesthetic, tactile, and auditory perception. He would be required to perform negligible cognition in order to know whether the right key had been hit. (A hunt-and-peck typist, on the other hand, would behave quite differently.)

The process of design and selection of interaction techniques for a task must take into account the perceptual, cognitive, and motor processes involved in carrying out the task, even when these seem to be trivial. In general, the design goal is to minimize the time taken by each of the three processes, although this cannot always be measured in the case of cognition. At the same time consideration must also be given to learning time, especially for infrequent users of a system. In Chapter 2 we describe some factors to consider which can help achieve this goal. In Appendix A we present a way to diagram interaction techniques which can help to identify the perceptual, cognitive, and motor process components of a technique. Identification of the processes is an important first step in designing or analyzing a technique.

1.4. Reference Sources

In our search for relevant experiments, we have used the following bibliographies:

1. Ramsey, R.H., et al., A Critically Annoted Bibliography of the Literature of Human Factors in Computer Systems. Science Applications, Incorporated, May 1978. NTIS AD-A058-081.

2. Use of Computers in Human Factors Engineering, (A DDC-TAC-74-34 Bibliography), Defense Documentation Center, Defense Supply Agency, Cameron Station, Alexandria, VA. 22314.

3. Man-Machine Interaction (DDC-TAS-72-71), Defense Documentation Center, November 1972, distributed by NTIS.

4. Smithsonian Science Information Exchange, Man-Machine System Interfaces, Research Information Package KC18-71, September 1978.

Of these, we found Ramsey's excellent annotated bibliography to be the most useful.

We also used Lockheed's DIALOG system to search for relevant citations, and a few useful items were located. The data bases searched were: Dissertation Abstracts, NTIS Index, Psychological Abstracts, INSPEC, COMPENDEX, and SCISEARCH.

2. Measures of Ergonomic Quality

An effective interaction design is one in which a user carries out his work with minimal conscious attention to his "tools" (the paraphernalia of the interactive terminal and the command language) and maximal effectiveness at the intended work. It is free of distractions, and reasonably friendly. In an earlier paper [FOLE74] we characterized the ideal design as one which placed and structured the communication between man and computer according to the model of cooperative human-to-human conversation. We also indicated that it is one that minimized certain psychological blocks, particularly boredom, panic, frustration, confusion, and discomfort.

There are many approaches to use in achieving this goal. This report concentrates on those approaches which are at the "lexical level" of the interaction design process: selection of appropriate interaction techniques for each elementary task which needs to be accomplished by a user. As we have said, our goal in this report is to rationalize the process of selecting the interaction techniques by which the user carries out his elementary tasks. The technique selected may involve the unadorned use of a physical input device, but most often involves modification, through software, of the device characteristics to make the process more natural, more interactive, easier and more satisfying to carry out.

This chapter is concerned with the criteria by which techniques can be compared, and by which such a selection can be rationalized.

Of course, satisfaction of these primary criteria is not accomplished at this lexical level alone. The context of the task and hence of the technique by which it is accomplished is also significant. Particularly, the techniques normally being selected are significant. In our view, the quality of an interaction design is determined by some combination of the following primary design criteria:

1) The time any particular user must spend accomplishing a particular project which the design is intended to support,

2) The accuracy with which that user can accomplish that project, and

3) The pleasure which that user derives from the process.

In a pure-production, low creativity environment, the third criterion may not be judged to be important, while in a creative, voluntary environment, maximization of that factor may be the dominant goal. Normally a design criterion will be a combination of the above primary criteria, with the greater weight applied to the project time.

The relationship between a task and its most advantageous technique is also influenced strongly by user experience and knowledge. A knowledgeable user requires a wider range of facilities, and will normally expect to be provided with finer, more precise tools than a less know-

ledgeable user before he will regard the design to be either efficient, accurate, or pleasurable. The experienced user can tolerate a much higher apparent "memory load" with many fewer prompting features. Indeed, evidence indicates that a system design which works well for the inexperienced user can be unproductively slow, crude, and displeasing to the experienced user.

Finally, the relationship between a task and its most advantageous technique is influenced by the particular characteristics of the physical devices by which they are implemented. A three-dimensional positioning device which achieves its full range by large linear motions will be more satisfactory for implementing some techniques than one whose motion is in a small physical range and involves some rotary action in its natural motion, and vice versa. This will be true even if both devices have the same resolving power, measured as a fraction of full range. The physical devices available must be considered before selecting the techniques which depend on them.

In summary, then, the primary performance criteria will be met in different degrees by the same technique, depending on:

1) The context of the task among temporally adjacent tasks and the existence of g,obal patterns of task sequencing,

2) The experience and knowledge of the intended user, and

3) The physical characteristics of the devices available for implementing the technique.

There is no one technique which is ideal for all instances of a given task. The data presented in this report are designed to aid in the evaluation of these dependencies.

2.1. Primary and Secondary Criteria

The three primary criteria (speed, accuracy and pleasurability), are influenced through a number of secondary criteria which are more easily measured and used to predict performance than the primary criteria. The secondary measures of ergonomic quality which appear to be most influential are:

1) Learning time,
2) Recall time,
3) Short term memory load,
4) Long term memor load,
5) Error susceptibility,
6) Fatigue susceptibility,
7) Naturalness, and
8) Boundedness.

2.1.1. Learning, Recall and Memory

Perceptual learning time is the time it takes for a user to learn the patterns that are to be used as signatures for the elementary figures and sounds that make up the technique. This learning has already taken place in childhood for many of the common visual signatures, such as alphabetic characters from a pen strokes and depth from a perspective drawing. Cognitive learning time addresses the time it takes to learn to use the technique to achieve the desired effect, while motor learning time is the time it takes to achieve the necessary physical skill to carry out the action.

Similarly, recall time measures the ease with which a user regains competence after a period of disuse of the technique.

Techniques will differ in the amount of perceptual, cognitive, and motor work they demand of the user, the rate at which they can be learned, and the rate at which they can be recalled. The measures of work are here thought to be measured in units of time, whereas the measures of learning and recall would be measured by either the amount of time it would take an inexperienced person to reach a desired skill level, or by the extent of improvement that is possible.

These times are somewhat vaguely defined. Clearly, there are degrees to the quality of learning. Has a hunt-and-peck typist "learned" the necessary motor skills to use a keyboard-based technique, or do we give that honor only to the touch typist, who is enormously faster? For our purposes, learning time can be measured as the time it takes to reach a skill level which allows the technique to be used in a practical sense.

Together with the experience of the user, these three factors determine an expected skill level of the user, and thereby affect the primary measure, task time. Task time can be estimated for low skills and for high skills, and the likely skill level can be estimated from the values assigned to learning, recall, and experience.

2.1.2. Memory Load

The load on the user's memory comes in both short-term and long-term forms. A technique has a high short term memory load when the user is obliged to retain unprompted knowledge of task elements over the duration of the technique. For example, if a technique requires the user to return an item to a place on the screen after he has manipulated it in some way, he is using short-term memory to remember the place until needed. If a prompting cursor were provided by the technique in question, then he would need to remember only the need for the action, and not the place.

Long-term memory is required to recall the details for using the technique. In other words, a technique involves a series of steps which usually must be remembered before the user can be said to "know how to use it". This information must be retained in long-term memory. It can be minimized by using techniques which have a small number of steps, and

a small amount of key information which must be retained. Regular patterns applied to all techniques (for example: subject, then verb--always), and prompting the actions as well as the data can also be useful in reducing long term memory load. Treu [TREU75] has demonstrated an approach to design based primarily on analysis of the required mental effort.

Memory load also can be divided into perceptual, cognitive, and motor components. short-term motor memory is, for example, that which is required by a user if he must move his hand back to an object he once had in his hand but has since released. Techniques which fail to preserve "tactile continuity" while using a physical device such as the mouse, which is normally out of the field of view, put additional load on short-term motor memory. The hand must be able to grasp the mouse with a minimum of groping. Short-term perceptual memory is required when one must identify particular signatures or images which otherwise have no long-term significance. Where a technique requires the identification of a like object on the screen, short-term perceptual memory is being used. Long-term perceptual memory is used in learning the key symbols of a technique, such as an appearing menu, and remembering the shape and identity of objects being manipulated over at least a span of several sequences of tasks.

The memory load associated with a technique influences the learning time, and also influences the ultimate skill associated with an expert user. When short-term memory load exceeds the capacity of the user (commonly when about seven "chunks" of information must be retained), the effect is low performance, and frustration. When long term learning requirements are high, learning and recall may be slow.

2.1.3. Fatigue and Error

The cognitive form of fatigue has many causes. Most often it is the result of insufficient variety in a regular task, displeasing stimuli, uncertainty, and unrealistic memory loads. Perception problems can also contribute to fatigue, primarily from visual and auditory clutter. Motor fatigue is primarily the result of poor mechanical design of physical devices, causing excessive need for muscular strength or causing cramping--action too small for the muscles being used. However, it can also be caused by techniques which too often or continuously place limbs in an unsupported position. Excessive use of a light-pen with a vertically mounted screen is the most common example.

Fatigue affects error rates and user satisfaction (pleasurability), and only indirectly affects task times by lowering memory capacity and slowing the reflexes. The literature describing the causes and remedies of fatigue, in all three forms, is extensive. Evaluation of individual techniques for their contribution to an overall fatigue level is made difficult by the apparent fact that the penalties associated with fatigue are not observed until fatigue-inducing factors exceed a certain threshold for a substantial interval of time.

2.1.4. Naturalness

We have grouped the two factors called naturalness and boundedness under the heading "convenience" because of their mutual strong effect on pleasurability. Naturalness is a factor which captures the idea of transfer of activity from other everyday activities. Pressing the foot to slow some operation down is an example of such a technique, taking advantage of analogy to activities most people do regularly. Naturalness is also a consequence of having input devices which coordinate displays in ways which are analogous to action-reaction in the real environment.

Thus, the selection of meaningful but familiar icons for light buttons enhances naturalness, as does the use of faces and facial expressions to display multi-parameter data. So also is the design of an orienting technique which uses a handle in such a way that a forward roll of the handle always produces a forward roll of the picture, and a leftward tilt always produces a leftward tilt of the picture [BRIT78].

It should be cautioned that our natural environment often provides conflicting models of natural behavior. For example, turning a steering wheel left causes the visual image (through the windshield) to move right even though the front of the car seems to go left. Hand calculators, providing numerals increasing upwards from "0", with "1", "2", "3" in a row immediately above "0", increase downward; while a telephone touchpad increases downward through "9" to "0", placing the numerals "7", "8", "9" in a row immediately above "0". Nevertheless observation and a sensitivity to environmental cues can often suggest that one alternative is more natural than another.

Naturalness in perception tells us what visual forms to use. Naturalness in cognition puts facts or data in a natural order for analysis and thinking. Naturalness in motor activity coordinates devices with surroundings and context, and gives the user a proper sense of kinesthesia (force and stroke).

Boundedness is a measure of the size of the space over which one must work perceptually, cognitively, or mechanically. A perceptually bounded technique is one with a limited physical space over which the eyes must move to perceive relevant information, and space of sounds to which the ear must be attuned. A cognitively bounded technique limits the range of intellectual space (ideas, concepts, facts) over which the mind must roam to use the technique. Mechanical boundedness measures the distance over which the limbs of the user must move to use the technique.

2.2. The Effect of Context

It has been observed that techniques should not be selected in isolation from knowledge of the other techniques which are in use at approximately the same time. An expression of a complete action generally involves a series of tasks to be carried out almost as if it were a

single unit. Indeed, Wallace and Foley [FOLE74] suggest that, analogously to human conversations, actions should be naturally grouped into action sentences. A user will, for example, select an object, position it at a desired location, and then affix appropriate labels to it "all at once".

Because of this phenomenon, designers must be careful, while selecting the technique by which all of the tasks are to be implemented, to take account of the devices likely to be in the user's hand and of the place where his visual focus is likely to be. Certain time- and memory-consuming suboperations can be avoided, and an otherwise inefficient choice of technique may suddenly become attractive. When a device must be switched in the hand, the selection of a location for the object in the previous example is slowed down by a significant extra motor activity. If the selection of the object requires the eyes to be focused off-screen, then there is another perceptual activity involved in identifying a place on the screen to which to move it, compared to an alternative (such as light buttons) in which the eye is already focused on the screen.

For these reasons, knowledgeable designers often insist on one-device designs, and a set of techniques which is visually coordinated. The temptation is very strong not to analyze the techniques individually at all. It would be short-sighted to yield to that temptation, however. The proper approach is to consider each candidate technique in combination with the others that are likely to be used in sequence before and after it.

Such a selection process is difficult, but certainly rational, since more alternatives are considered and those alternatives are considered in the light of the other performance criteria.

Work will be needed to more systematically incorporate these considerations into a more global approach to the design of interactions. Preliminary study shows that, through more detailed analysis of the substeps of a technique (for example, using the task diagram described in Appendix A), the advantage of combined techniques to the perceptual, cognitive, and motor activity can indeed be quantified. This is shown quantitatively in the recent work of Card, Moran and Newell [CARD80].

2.3. The Effect of User Experience and Knowledge

It is also clear that experienced users require different choices. The effect of user experience and knowledge can be hypothesized to result in a compression of perceptual and motor functions to a much greater degree than cognitive functions. If this is true, then an analysis of the perceptual, cognitive, and motor components of perfor-

mance of a technique can be used to estimate relative merit for use by

1) a new user, or
2) a skilled user

by simply comparing

1) total activity, or
2) cognitive activity

alone. The hypothesis needs to be tested, but preliminary comparisons appear to show consistency with intuition.

3. Interaction Tasks and Techniques

We suggested in Chapter 1 that interaction sequences can be decomposed into a series of basic interaction tasks. These tasks appear to be of only six distinct types, each of which we will describe in turn. Each interaction task has a set of requirements. For instance, a positioning task may require dynamic, continuous feedback using a screen cursor. A property of interaction techniques for positioning is the type of feedback they can provide. In the case at hand, only interaction techniques providing dynamic feedback would be considered candidates for implementing the positioning task.

Interaction techniques not only have requirements but also have hardware prerequisites which must be provided; otherwise, the technique can not be considered. A positioning technique which provides dynamic, continuous feedback and allows movement in arbitrary directions must be supported by a continuous-motion input device such as a tablet, light pen, or touch-sensitive panel. Furthermore, the display device itself must be able to update a cursor position twenty to thirty times per second. In design situations where interaction devices have already been selected, these prerequisites serve to limit the set of interaction techniques which can be considered. When device selection is part of the design process, the prerequisites serve to link a technique being considered with required hardware characteristics.

In this chapter we discuss the six types of interaction tasks, enumerate the requirements which each task may have, show how the requirements relate to the properties of interaction techniques, and in turn show how a technique's hardware prerequisites affect device selection. We also present an overview of existing interaction devices and their functional characteristics. Then in Chapters 4 and 5 we go on to describe and evaluate various interaction techniques.

3.1. Interaction Tasks: Types and Requirements

An examination of interactive graphics leads us to conclude that there are six fundamental types of interaction tasks. The tasks, which are application and hardware independent, form the building blocks from which more complex interaction tasks, and in turn complete interaction dialogues, are assembled. The tasks are user-oriented, in that they are the primitive action units performed by a user. They relate to, but differ from, the logical input devices found in device-independent graphics packages [GSPC79, CARU77] and discussed previously by the authors of this report [FOLE74, WALL76] and in [NEWM68], because the logical input devices are hardware and software oriented, rather than user oriented.

The six interaction tasks are:

1) Select
2) Position
3) Orient
4) Path
5) Quantify
6) Text

These are similar to the tasks described in RAMS79 and in OHLS78. The set of tasks is based not on fundamental research into users' underlying cognitive processes, but rather are based on experience with dozens of interactive graphics systems and a subsequent categorization of observed interaction activities into these six categories. Refinement and restudy of the tasks is a key step for future research.

3.1.1. Select

The user makes a selection from a set of alternatives. The set might be a group of commands, in which case typical interaction techniques are:

1) Menu selection using a light pen,
2) Menu selection using a cursor controlled by a tablet,
3) Type-in of command name, abbreviation, or number on an alphanumeric keyboard,
4) Programmed function keyboard, and
5) Voice input of the selection name.

Rather than being commands, the set of alternatives might be a collection of displayed entities which form part of the application information presentation. In a command and control application, the entities might be symbols representing troop and equipment positions.

Interaction techniques which might be used in this case are similar to those for command selection:

1) Selection by pointing, using a light pen,
2) Selection using a cursor controlled by a tablet,
3) Type-in of the entity name,
4) Selection by pointing, using a touch-sensitive panel, and
5) Voice input of the entity name.

Figure 3.1 shows the set of selection techniques which are discussed in the next chapter. As with all six interaction tasks, we do not discuss every conceivable technique, as their number is limited only by one's imagination. Rather, we limit the discussion to those techniques which have been proven in use.

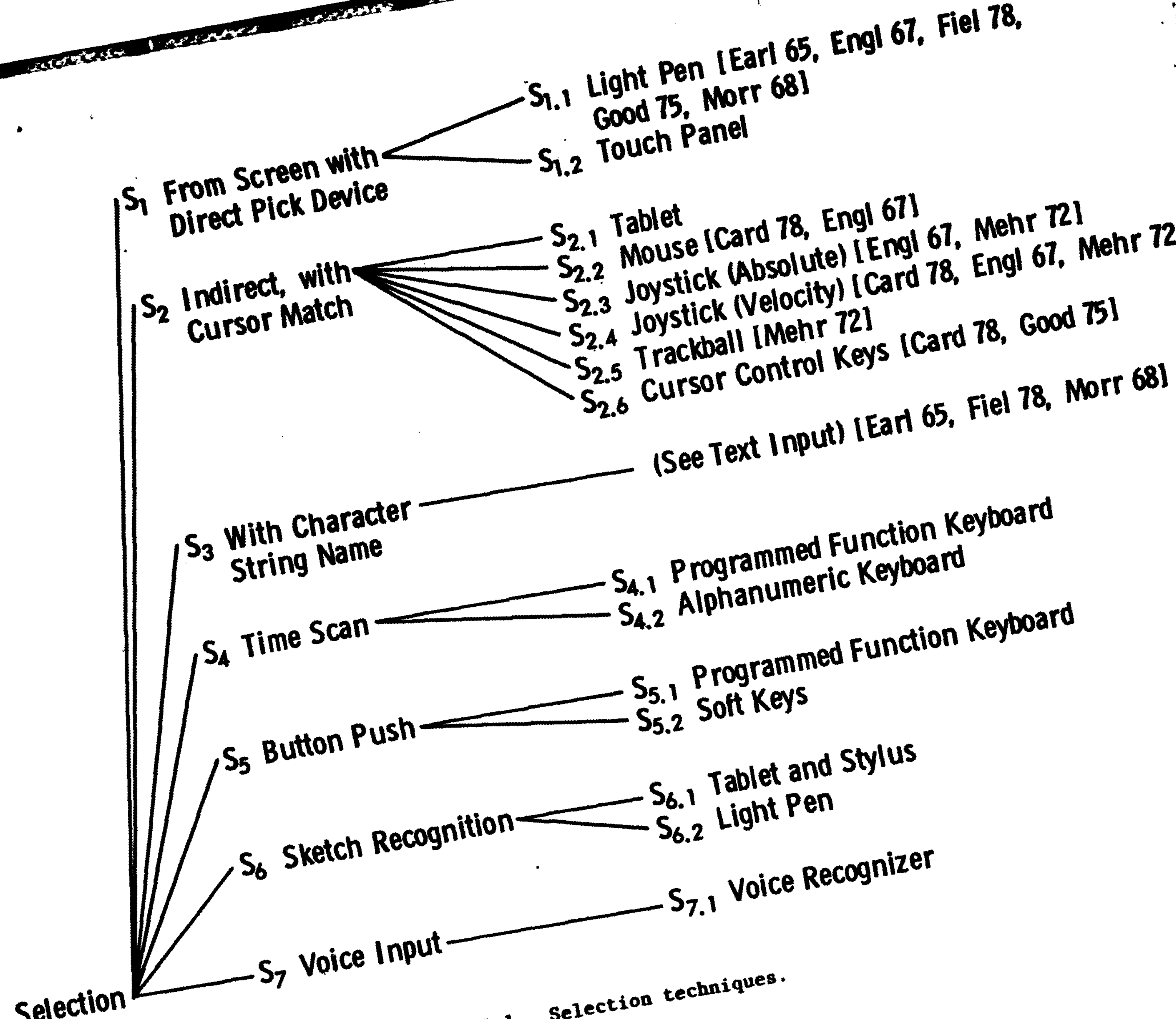


Figure 3.1. Selection techniques.

The application requirements for a selection task are:

1) Size of the set from which the selection is made, if size is fixed, and

2) Range of set size, if variable.

Rather different techniques might be best for selection from a fixed set of two choices (such as "YES" and "NO") and for selection from a very large, variable sized set of displayed entities.

3.1.2. Position

In carrying out the positioning task the user indicates a position on the interactive display. This is typically done as part of a command to place an entity at a particular position. Customary interaction techniques for positioning are:

1) Use of a cursor controlled by a tablet, mouse, or joystick,
2) Type-in of the numeric coordinates of the the position, and
3) Light pen and tracking cross.

Figure 3.2 shows the positioning techniques we discuss.

The application requirements of the positioning task are:

1) Dimensionality: 1D, 2D, or 3D. Positioning in 1D simply means that the position specified is constrained to be along some line.

2) Open-loop or closed-loop. In the former case, the user knows in advance the exact coordinates of the position, so visual feedback of the position on the display is not an essential part of the process of specifying the position. In the latter case, visual feedback is important because the user adjusts the position, based on the feedback, until the desired end result has been achieved. (This is the distinction between the "discrete positional" and "continuous positional" tasks proposed in [RAMS79].)

3) Resolution expressed as parts of accuracy over the maximum range of coordinate value. An accuracy of .01" over a range of 10" is one part in 1000.

3.1.3. Orient

The user orients an entity in 2D or 3D space. For 2D, this might mean rotating a symbol to be heading Northnortheast. In 3D, it could mean controlling the pitch, roll, and yaw of the view of a terrain model.

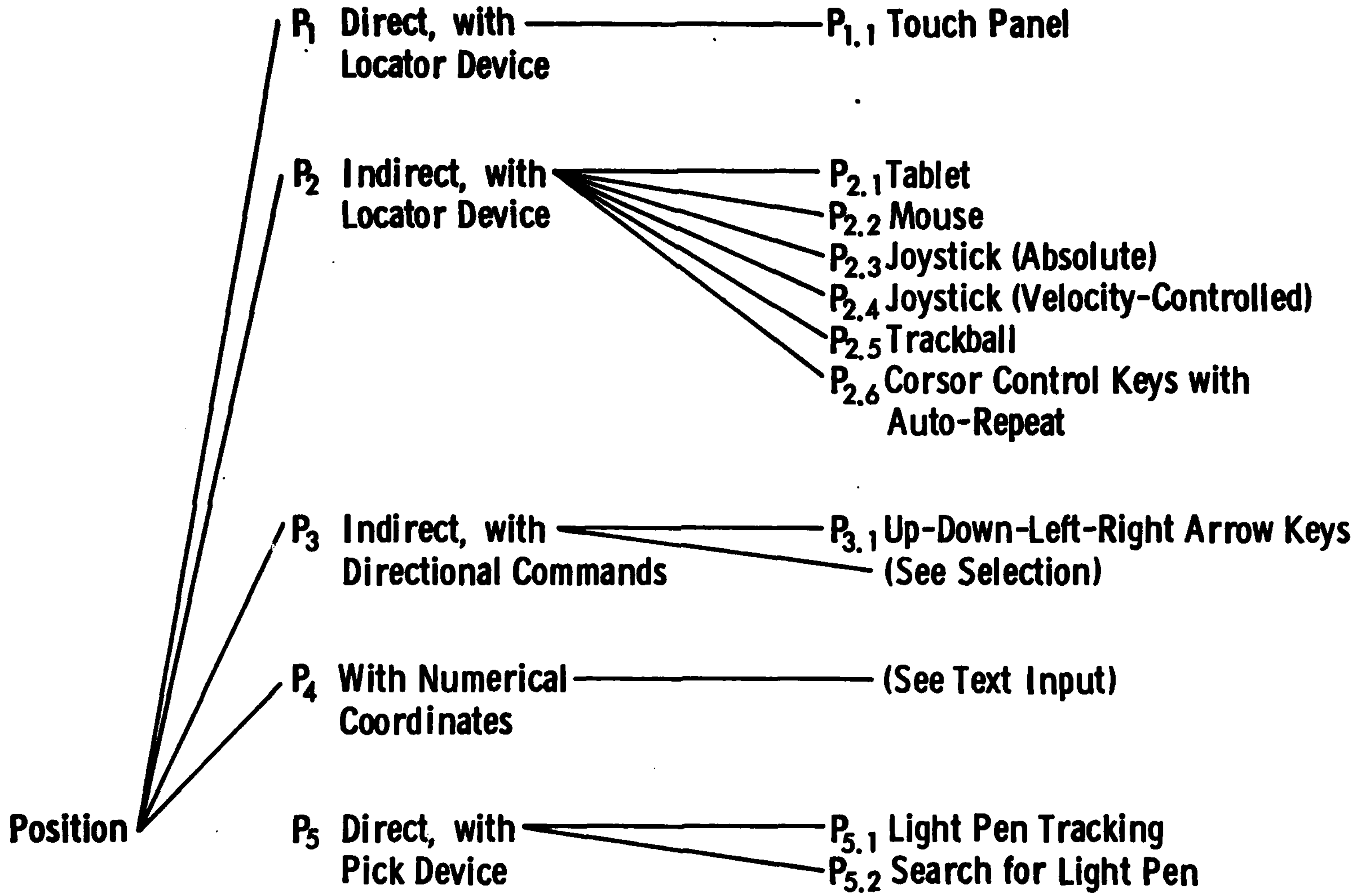


Figure 3.2. Positioning techniques.

Interaction techniques useful for the orientation task include:

1) Control of orientation angle(s) (one angle for 2D, up to three angles for 3D) using dial(s) or joystick, and

2) Type-in of angle(s) using alphanumeric keyboard.

Figure 3.3 shows the different interaction techniques used to implement an orient task.

The requirements of the orientation task are analogous to those for the positioning task. Dimensionality is replaced by the more general term "degrees of freedom", values of which can be one, two, or three. Of course it is only in a 3D space where two and three degrees of freedom make sense: in 2D, only a single degree of rotational freedom is available. On the other hand, one degree of freedom in 3D makes perfectly good sense: it is a rotation about an arbitrary axis.

3.1.4. Path

The user generates a path, which is a series of positions or orientations, created over time. A path is considered a fundamental interaction task, even though it consists of other primitive tasks (position or orient) because another fundamental dimension--time--is involved and because we believe this changes the user's perception of the task. With a single position or orientation, the user's attention is focused on attaining a single end result. In the present case, by contrast, it is the series of positions or orientations, and their order, which is the focus of attention.

A path of positions might be generated by a user in the process of digitizing a sketch, of indicating the routing of a run on a printed circuit board, or of showing a desired route on a map. A path of orientations (and of positions) would be generated in a simulated flight over a terrain model.

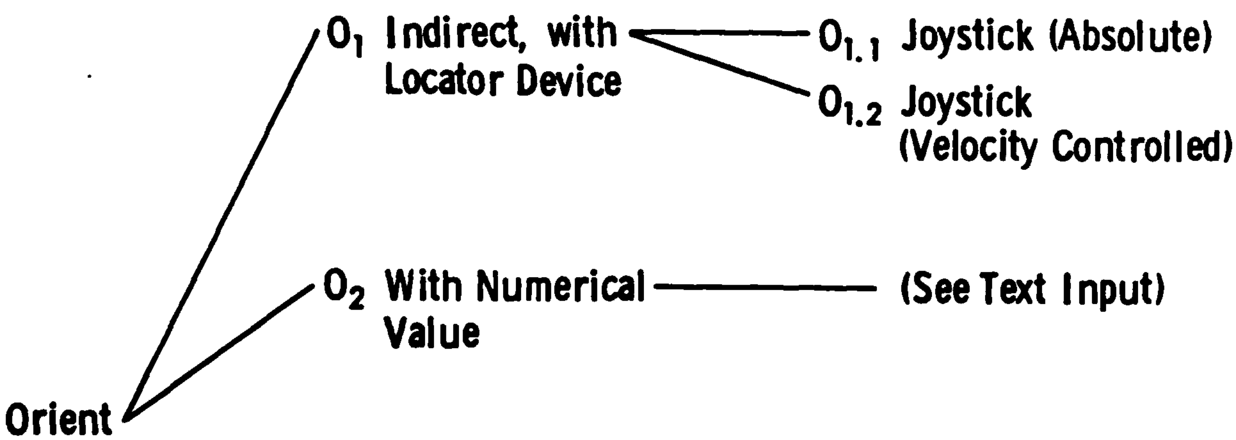


Figure 3.3. Orienting techniques.

The techniques for generating a path are usually those position and orient task techniques which allow closed-loop feedback, and typically involve use of a tablet, mouse, joystick, and/or dials. In some cases open-loop techniques might be suitable.

The requirements of a path task are:

1) Maximum number of positions or orientations along the path, if they are to be saved. For instance, positions would be saved when digitizing a shape, but might not be saved in a flight simulation.

2) The interval between each element on the path, and its basis. Some paths are time-based, with a new element entered at each periodic time interval (typically 33 msec. for a real-time simulation). Other paths are distance-based, with the next element entered each time it differs from the preceeding element by a predefined amount.

3) Dimensionality: 2D or 3D.

4) Open-loop or closed-loop.

5) Resolution.

6) Type: position, orientation, or both.

3.1.5. Quantify

The user specifies a value (i.e., number) to quantify a measure, such as the height of an entity, or the value, in ohms, of a resistor. Typical techniques are:

1) Value type-in on a keyboard, and
2) Rotary or slide potentiometer.

Figure 3.4 shows the set of quantifying techniques we shall discuss. The requirements of a quantification task are:

1) Resolution, expressed as number of resolvable units to be specified. For instance, age in years would require about 120 units of resolution, while angle in degrees requires 360 units.

2) Open-loop or closed-loop

3.1.6. Text

The user inputs a text string, used for example as an annotation on a drawing, or as part of a page of text. The key factor is that the text string itself becomes part of the information stored in the computer, rather than being used as a command or being converted to a value, position, or orientation. In the first case, the text input is a new interaction task, while in the latter cases, the text input is being

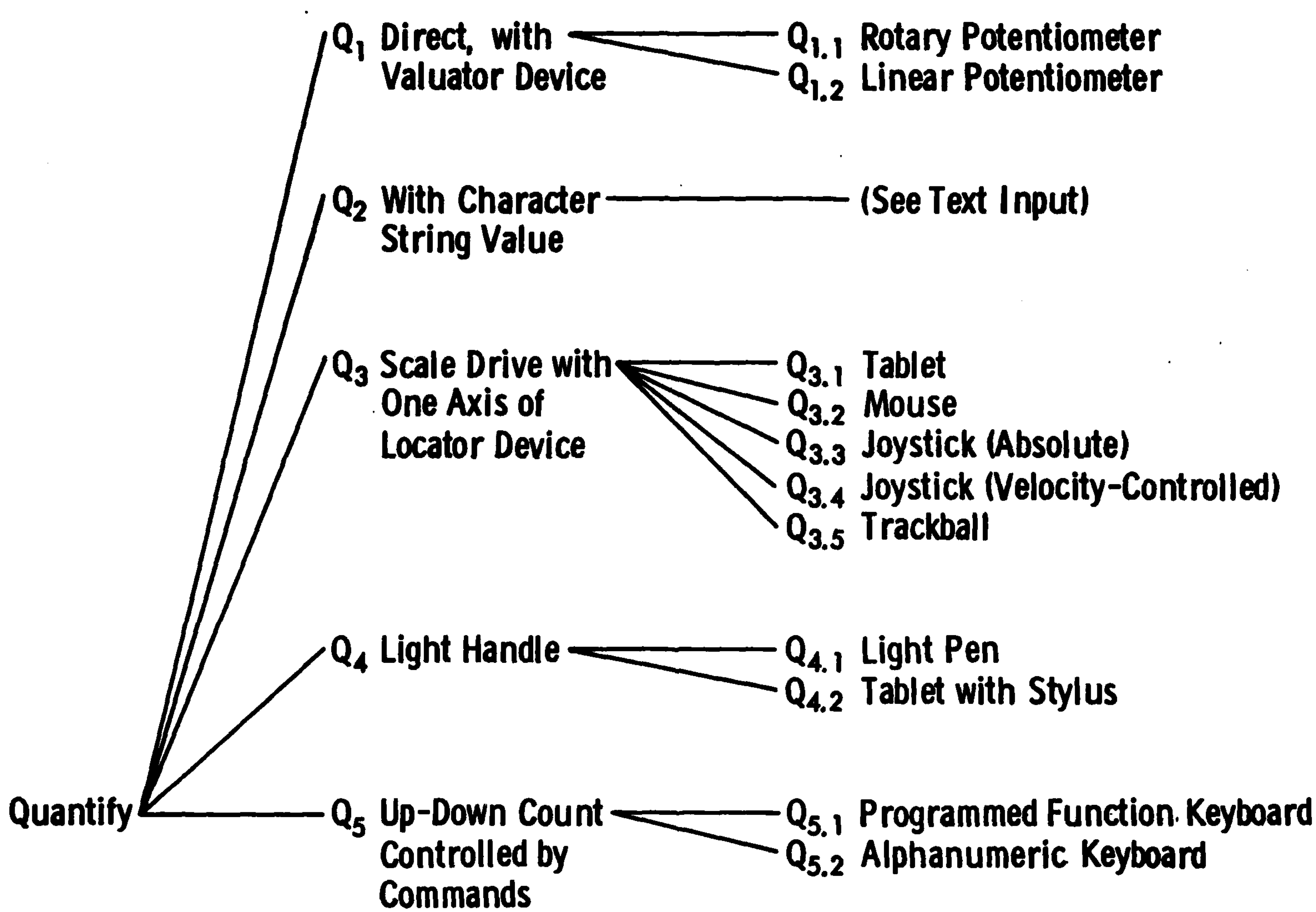


Figure 3.4. Quantifying techniques.

used as an intermediary for one of the other interaction tasks. Typical interaction techniques for text input are:

1) Type-in from an alphanumeric keyboard, and
2) Character selection from a menu

Figure 3.5 shows the text-entry techniques to be discussed in Chapter 4.

The text task has three requirements. They are:

1) Size of character set
2) Maximum length of string to be entered

There are other issues surrounding the text input task, such as the specific character set (as opposed to its size). Such issues, however, do not affect the choice of technique or device. The details of the character set would affect only the labels on key caps, for instance.

3.1.7. Summary

We have proposed that user interactions can be grouped into six task catagories.

Each task is implemented in practice by an interaction technique. While there are many interaction techniques to consider for each task, the task requirements limit the choice of techniques to those whose properties match the task requirements. The set of requirements for each task is derived from an analysis of the needs of the application being implemented. Table 3.1 summarizes the requirements for each task.
.se Controlling Tasks

None of the six interaction tasks described in the previous section directly modifies the objects being displayed. If such a modification is intended, it can be achieved interpreting a selection (in particular, a command selection) to invoke a picture-modifying program, using as operands data developed from other, earlier or later, tasks.

There are, nevertheless, a number of tasks which have as their basic purpose the control of objects which are already visible on the display. They are elementary, in the sense that the user cannot divide them into a sequence of other elementary tasks. They are, on the other hand, closely related to the tasks we have already described. We refer to them as controlling tasks, because they characteristically control something, rather than specify something (as do the elementary tasks). There are four such controlled tasks, which are named for the type of modification they effect on an object:

1) Stretch
2) Sketch
3) Manipulate
4) Shape

Techniques for implementing these tasks will be called controlled techniques.

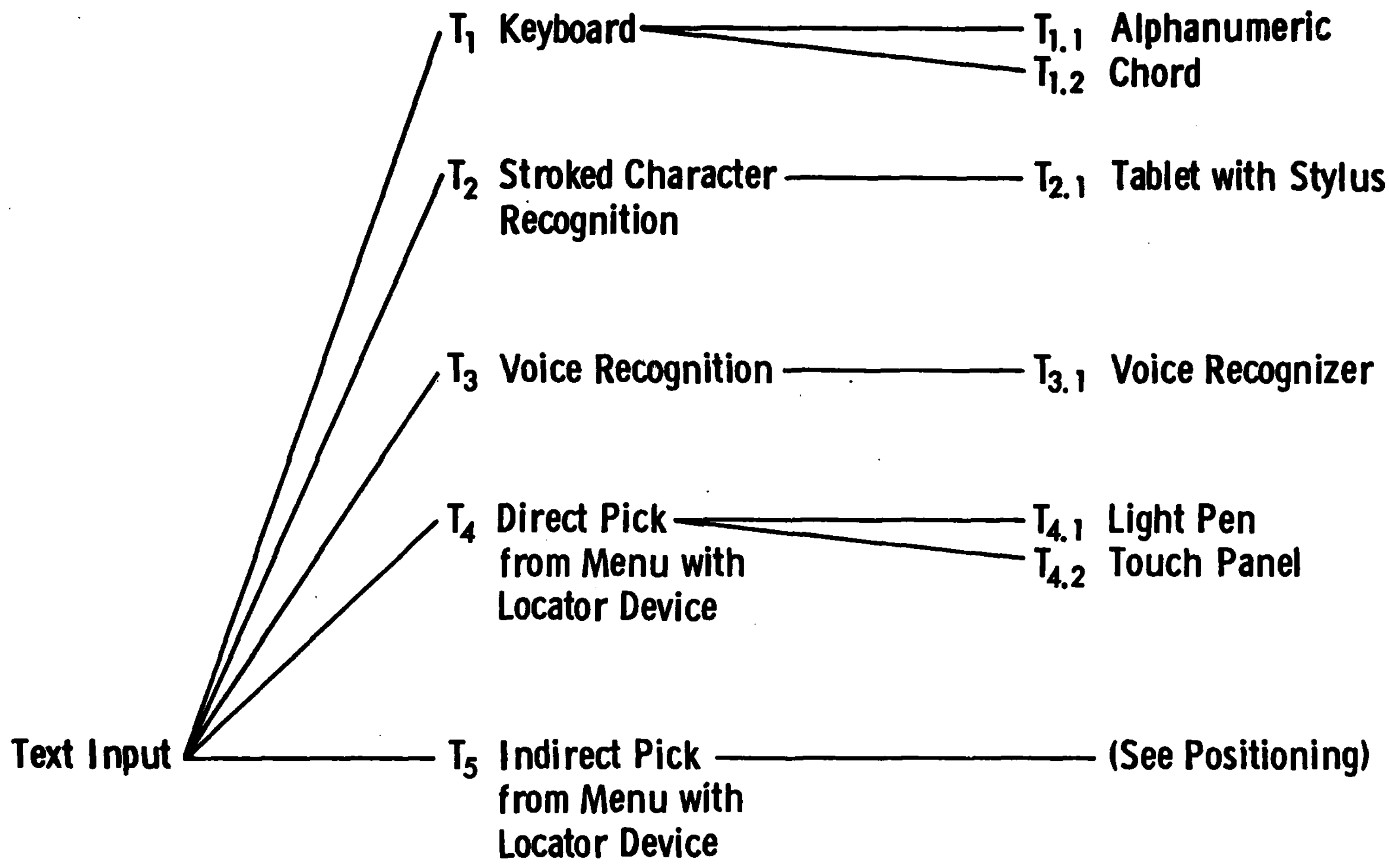


Figure 3.5. Text-entry techniques.

3.1.8. Stretch

The user grasps a particular feature and moves it to a new position, leaving remaining features of the object in place. The result is a distortion of the shape of the object, much like stretching a rubber mask or a collection of rubberbands. Typical stretching techniques are:

1) Stretched lines,
2) Stretched horizontal or vertical lines,
3) Stretched vertices (lines posessing a common endpoint),
4) Horizontal-vertical connections (called a zig-zag--see Sec. 5.1), and
5) Stretched polygons, prisms, and pyramidal forms.

These techniques are all based on positioning techniques, and carry the same prerequisites and requirements as for positioning. They are most useful when the feedback is continuous, but can exist in both continuous and discrete feedback forms.

3.1.9. Sketch

The user, by manipulating a locating device like it were a brush or pen, causes an object to be created by freehand sketching. Line structure (thickness, dot-dash character, color, etc.) may be specified as part of the brush form.

Sketching can be viewed as the controlling version of the path task. It shares all forms and requirements of the pathing task, plus a line-style or brush-form requirement, which specifies the attributes of the sketch lines left behind on the screen after the device motion has taken place.

3.1.10. Manipulate

The user causes an object to move about in the viewable space, by either translation or orientation under the control of an input device (a locator). Scaling has been arbitrarily included as a variant of this task.

Techniques for manipulation are described as either dragging, twisting, or scaling, depending on whether they are based on translation, orientation, or valuation techniques. The first two differ from the elementary technique because the cursor or gnomen is replaced by an already existing object on the screen.

3.1.11. Shape

The user causes a smooth, curved line or surface to change its general shape according to the placement of a positioning control.

Techniques for shaping are described in greater detail in Section 5.4.

Table 3.1

Summary of Interactive Task Requirements

Interaction Task	Requirements
Select	Size of set, if fixed Range of set size, if variable
Position	Dimensionality: 1D, 2D or 3D Resolution
Orient	Degrees of freedom: 1, 2, or 3 Open-loop or closed-loop Resolution
Path	Maximum number of path elements to be retained type of interval between each element on path Size of interval between each element on path Dimensionality: 2D or 3D Open loop or closed loop Resolution Type: position or orientation or both
Quantify	Resolution Open-loop or closed-loop
Text	Size of character set Maximum length of string

3.2. Organization of Interaction Techniques

Having in the previous section discussed interaction tasks, we now turn our attention toward the interaction techniques used to implement the interaction tasks. Figures 3.1 through 3.5 show how we have organized the techniques to be discussed in Chapter 4. The lists of techniques are by no means exhaustive, but we believe the organization will easily cover other techniques as well.

3.2.1. Techniques and Their Variations

At the first level in these tree-like diagrams we have the fundamentally different techniques, such as menus and command type-in for the selection task in Figure 3.1. At the second level are variations on a basic technique, such as the specific physical device used to drive the cursor for selection from a menu (see Figure 3.1).

In some cases, where the technique draws on other techniques normally associated with other interaction tasks, the diagrams simply refer to another diagram.

3.2.2. Technique Parameters

There is another aspect to interaction techniques which is not shown in these diagrams but which does affect the characteristics of individual techniques. This is the aspect of technique parameters, specific examples of which are:

1) The form of the cursor used in connection with some of the positioning and selection techniques,

2) The ratio of hand movement to cursor movement when a tablet, joystick, mouse, or other physical positioning device is used, and

3) The layout of a menu as either a row, column, or grid of choices.

One might include hardware device characteristics, such as the length or diameter of a joystick, as technique parameters. However, following our basic tenet of taking hardware as a fixed given, we do not do so. Instead, we limit technique parameters to those aspects of a technique which are normally controllable by software.

In Chapter 4, where specific techniques are discussed, we describe some technique parameters. As with basic techniques themselves, the types of parameters associated with one or more techniques are limited only by our imagination and creativity. Accordingly, we cannot be exhaustive, but rather attempt to address the most substantial parameters, especially those for which human factors literature offers guidance.

Each of the techniques (as opposed to technique variations) has a set of hardware prerequisites, with respect both to the display technology as well as to the types of devices used with the technique. These prerequisities are described with each technique. A typical prerequisite, say for a closed-loop positioning technique, would be for a continuous movement physical device as well as for a display on which the feedback to the user can be dynamically repositioned 15 to 30 times per second.

4. Interaction Techniques

We have in the previous chapters set forth a framework for the discussion of interaction techniques: a framework provided by the semantic-syntactic-lexical trichotomy, placing the selection of interaction techniques at the lexical (and hence final) stage of design. At this lexical level, we deal with six interaction tasks, and organize the techniques according to the task they fulfill. In this present chapter we provide detailed descriptions of many of the techniques shown in the Interaction Tree Diagram of Figures 3.1 to 3.5. The goal of this presentation is to bring out some of the human factors issues which are germane to the design of the techniques, and to discuss any experiments which are relevant to the process of selecting one technique in favor of another.

4.1. Selection Techniques

A selection technique typically involves picking an item from a list of alternatives. Typical applications are command selection and operand selection. An inherent pick device is the light pen. Any positioning device can be used to simulate a pick, by placing a cursor on top of a displayed representation of the selection desired.

4.1.1. Command Selection

A menu of commands is displayed, typically in list form. The desired command is selected from the presented set of alternatives. Direct selection devices such as the light pen or the touch panel, or a device which can simulate selection, such as an alphanumeric keyboard or physical locator, can be used.

Menu selection is most commonly used for command entry. There are also "operand" menus, e.g., a menu of capacitors, resistors, etc., for a circuit design application.

Several variations on the use of menus transcend which specific technique is used for selection:

1. Organization of a menu: single level vs. hierarhical

If the set of alternatives is small enough to be contained in the space the screen provides, a single-level menu can be used. Otherwise, there are two possibilities: a hierarchical menu or a single-level menu requiring several sequentially-displayed screens to view. In either case, "navigational aids" will be needed to move through the selections.

With a hierarchy, a phase is first chosen from the "main" displayed menu, and the desired specific subphase is then selected from the subsequently displayed menus until the command is found. Sometimes the user

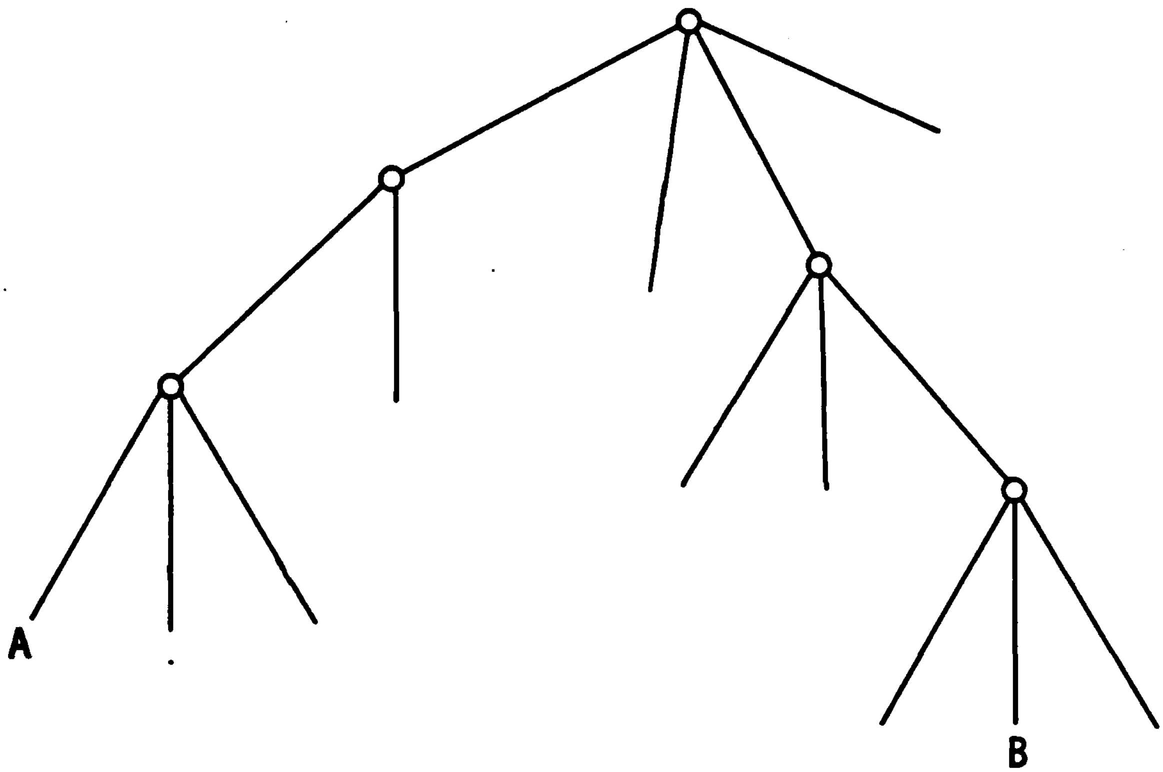


Figure 4.1. A four-level hierarchy menu tree.

has to go through several menu phases and subphases before the desired entry can be found. Applications may also require the user to frequently refer back to the main menu before another command selection can be made.

Suppose an application has a four-level hierarchy tree defined by the phases as shown abstractly in Figure 4.1. The leaf nodes of the tree represent the commands, while the internal nodes represent groups of commands. When a selection is made, we travel down the tree from its root toward its leaves. Each selection moves us one level further down, until a leaf (i.e., a command) is reached. Suppose the command A has been selected, and command B is desired next: the user must be provided with the controls to climb back up the hierarchy to the root, and then descend toward B. This can be done by control commands such as "move to the top of the hierarchy," and "move up one level in the hierarchy." If the tree is too big, the capability of going directly to a few frequently-used nodes of the tree is particularly useful.

In the case of a single level menu, commands are needed to "flip pages" forward and backward. Each of these commands, as well as those for traversing a hierarchy, represents another selection task. That is, a single complex selection task has been converted into a larger number of simpler (but potentially still complex) selection tasks, simply because of space limitations on the display.

2. Menu item order

There are several ways of sequencing command entries in a menu:

a) Alphabetical organization, to help the user locate a given selection.

b) Organization by the frequencies of entry use, with the most frequently-used appearing in the front part of the menu. The objective is to minimize search time, given that the user knows which command is desired and does not need first to search the entire menu.

c) Logical organization (placing entries of the same category together to form a group of logically related commands). Again, the idea is to decrease search time, by "chunking" commands together in ways that make sense to the application. This is certainly the way that commands would be grouped in a hierarchy.

All three ways can be used together or separately to construct menus [UBER68].

3. The representation of a menu: iconic vs. textual

While menus are often in text form, they can also be in graphic form. A set of graphical symbols, known as icons, can be used to represent commands (Figure 4.2) or for operands (as in Figure 4.3).

Iconic menus can be designed to occupy less screen space than do text menus, giving more compact menus. Icons can decrease the cognitive load of menu selection, if the icons are immediately more evocative of their meaning than the equivalent text string.

4. The position of a menu: static vs. moving

A display menu can be static or moving. A menu which is always in the same position on the display screen is called a static menu. A static menu can be:

a) Part of the same screen as the main display.

b) On an auxiliary screen next to the screen with the main display.

c) On the same screen as the main display, but in place of the main display, so the user has to switch back and forth.

d) Printed on a tablet.

The imprinting of a menu on a tablet is used for fixed-application systems. One general use of this technique is to imprint a keyboard image on the tablet to simulate "type-in" for users who don't type. The

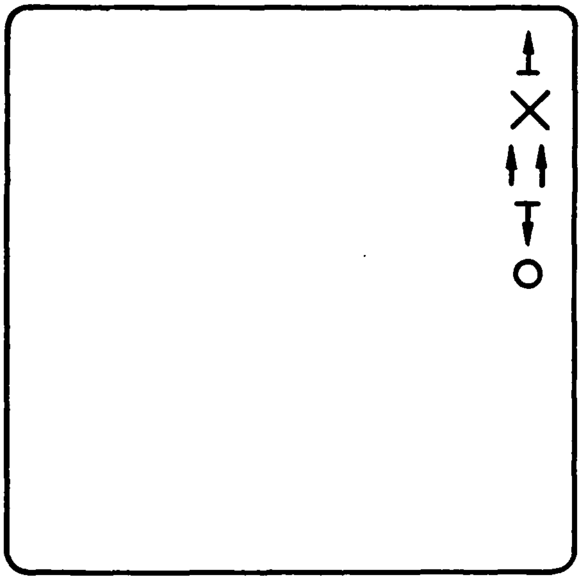


Figure 4.2
An iconic command menu.

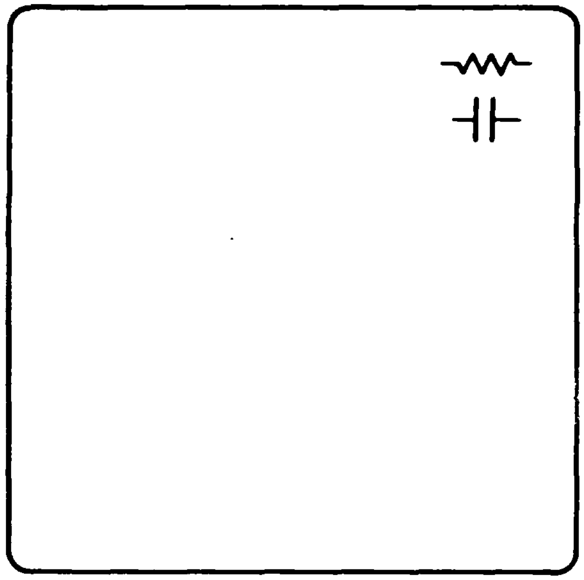


Figure 4.3.
An iconic menu for operands.

use of a tablet or an auxilliary screen implies that the user has to look away from the application display, hence destroying visual continuity. The advantages are the saving of display space, which is often at a premium, and the accommodation of a large set of commands, which is often not possible to achieve by just using the application display.

An appearing or moving menu is one which appears when a selection is to be made, and when a positioning device can be considered for implementing the selection. The menu always appears near the screen cursor, which is usually in the vicinity of the user's visual attention. Figure 4.4 shows an example of a moving menu. A moving menu, although it preserves visual continuity, cannot take advantage of muscle memory

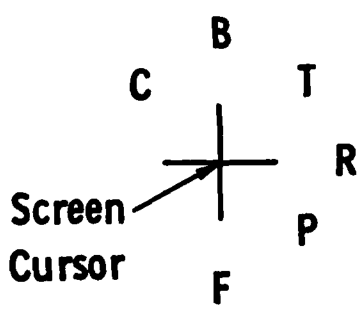


Figure 4.4. A moving menu.

as the static menu technique. However, it has the advantage of requiring only minimum hand movement when a user does make a selection.

5. Menu organization: horizontal, vertical, blocked

Menus can be presented as vertically or horizontally oriented selections. Both COFF61 and EARL65 show no difference between horizontal and vertical for searching through a list. The items also can be grouped into clusters, with extra space between the groups. [CROP68] showed such grouping to be effective in improving search time in tabular data. Anecdotal reports (James Thomas, Battelle Northwest) verify this.

6. Target size (Fitts' Law): Display targets, whether alphanumeric or iconic, should be as large as possible in order to reduce positioning time and error rate. This recommendation is given based on the experimental evidence of Fitts' Law, which predicts that the hand movement time to position a target from one location to another increases with the distance moved and decreases with the size of the target [FITT66, CARD78].

To pick an entry from a menu, many interaction techniques and variations of techniques are commonly employed. We limit our discussion to some commonly used techniques.

(a) Command Selection With Character String Name - Name Type-In

Summary: A command menu is displayed. The desired command on the menu is typed in using an alphanumeric keyboard. In this case the menu is solely a memory aid, used more as a prompt than as an integral part of the command entry process.

(b) Command Selection by Label Type-In

Summary: The label associated with a menu item is typed in.

Prerequisite Devices: Text-entry device.

Description: This technique is an enhancement of the Name Type-In technique described above. A menu of system-defined commands and their corresponding label is displayed. To make a selection, the user types in the label representing the command instead of the command itself. The labels can be numeric codes or mnemonics. This shortens input time and reduces typing errors. The menu is still partly a memory aid; the experienced user remembers the label to enter without looking at the menu, while the inexperienced user consults the menu.

(c) Command Selection by Direct Light Pen Pick

Summary: The desired choice is picked from the menu.

Prerequisite Devices: Light pen.

Description: A light pen is used to pick the desired command entry directly from the displayed command menu. Pointing with a light pen for picking has a naturalness, lacking with most other devices.

(d) Command Selection by Touch Panel Pick

Summary: The user touches a finger to the screen on top of the desired menu choice.

Prerequisite Devices: Touch panel.

Description: The operator touches the screen to indicate the desired entry from the displayed menu. The prerequisite device for this variation is a touch sensitive panel. This technique is very attractive, because no intermediary device is needed. The user's finger becomes the picking device. The motor load is lower than for penpicking, because no device need be acquired prior to making a selection.

(e) Command Selection by Simulated Pick - Cursor Match

Summary: A cursor is moved on top of the desired menu choice, and a button depressed.

Prerequisite Devices: Positioning device.

Description: Other devices can be used to simulate selection by moving the displayed cursor close to the desired command. The system automatically matches the position of the cursor to the nearest command, taking it as the desired command to pick. Precise positioning of the cursor is not required. A simulated pick can be effectively accomplished with a continuous locator such as a tablet, a mouse, or a joystick. It can also be accomplished with a discrete locator (an up/down/left/right cursor) though it takes longer to select and can be very awkward.

(f) Command Selection by Function Key

Summary: A unique function key associated with the command is depressed.

Prerequisite Device: Function keys.

Description: A bank of buttons is used for input commands. Each button corresponds to a command.

(g) Command Selection by Button Push - Soft Keys

Summary: A button associated with a command is depressed to enter the command.

Prerequisite Devices: One or more buttons.

Description: Commands are presented as a series of labeled buttons. Depressing a button activates the command. So-called "soft keys," located on the edge of the display area, have their labels displayed on the screen, and thus can have their meanings changed quite readily.

(h) Command Selection by Voice Recognition

Summary: The user speaks the name of the selected command, and a word recognizer determines which of a set of known words was spoken.

Prerequisite Devices: Word recognizer

Description: The user voice-enters commands by speaking the command name, preceded and succeeded by silence, to a word recognition system.

This input method might be preferable for non-typists as an input means for alphanumeric data, provided that voice recognition technology is able to accurately recognize a large set of words, letters, and numbers.

Voice input is a simple means to distinguish commands from data; commands are entered by voice, the data by keyboard or other means. In a keyboard environment, this removes the need to distinguish data and commands for using characters or modes.

(i) Command Selection by Sketch Recognition

Summary: The user makes sequences of movements with a continuous positioning device. The sketch recognition system recognizes the sequence to determine what command is being entered (see also character recognition).

Prerequisite Devices: Any continuous positioning device, such as a tablet, a mouse, or a lightpen and tracking cross.

Description: Using a continuous positioning device, the user sketches a simple pattern. The sketch recognizer automatically matches the pattern with the set of defined patterns, each of

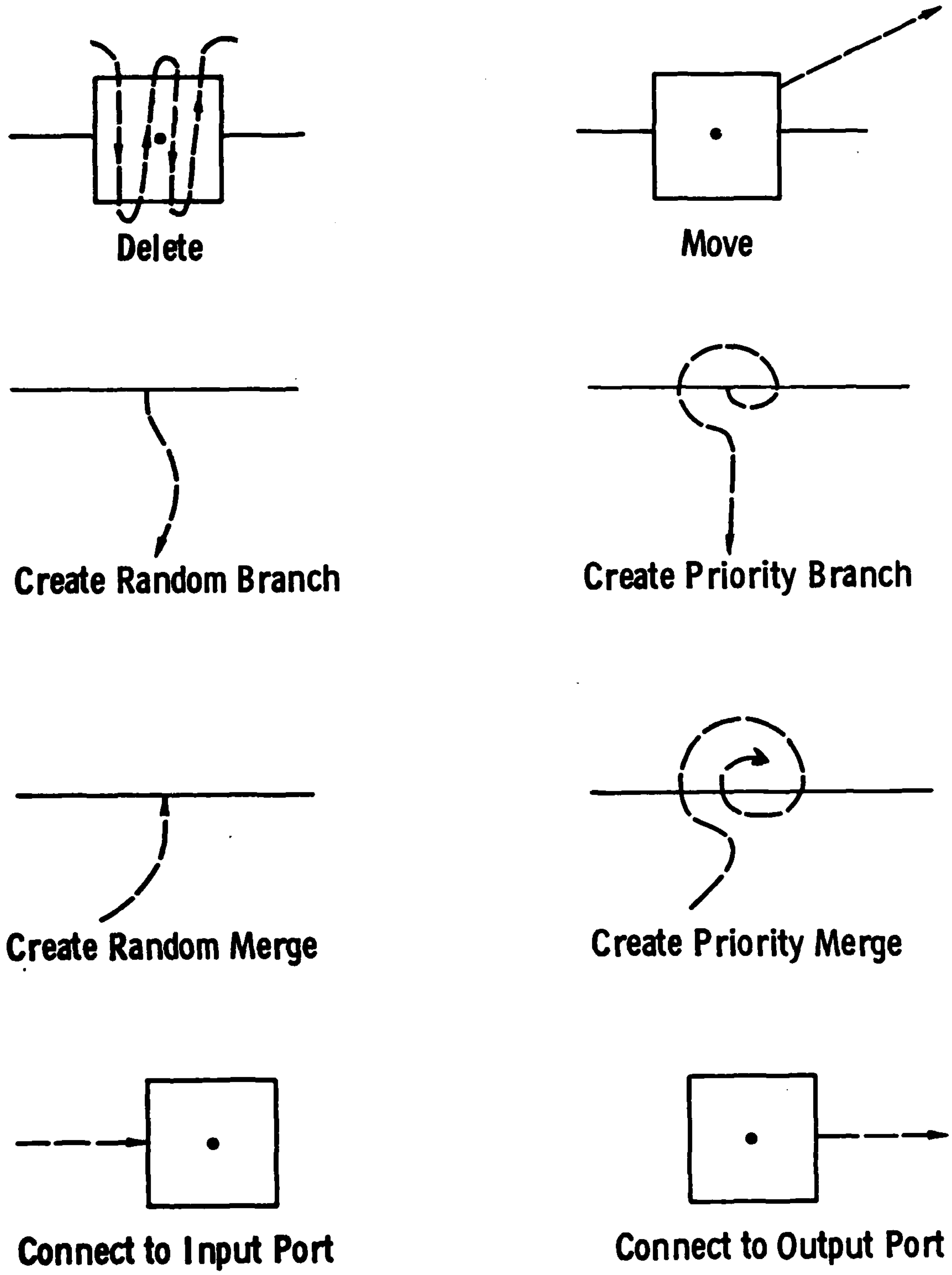


Figure 4.5. A series of sketch patterns.

which has an associated command. Figure 4.5 shows one set of sketch patterns and their related commands. Some of the commands are unique to the design of queuing networks, the application from which this example has been taken.

The technique requires no typing skill and preserves tactile continuity. Furthermore, if the command requires a position to be specified, the place where the sketch is done can serve as the position. Similarly, if an operand is required, the sketch can be done "on top of" the operand if it is part of the displayed image. Skilled operators can work very fast with this technique.

4.1.2. Operand Selection

(a) Operand Selection by Cursor Match

Summary: A displayed cursor is moved by a positioning device to select the desired operand. The system reads the position of the cursor and determines what the selected item is.

Prerequisite Devices: Displayed cursor, any positioning device.

Description: A positioning device such as a locator is used to move the displayed cursor close to the desired operand. The system automatically matches the position of the cursor to the nearest item, taking it as the desired selection. Precise positioning of the cursor is not necessary: it need only be placed nearer the item to be selected than it is to any other item.

(b) Operand Selection by Picking

Summary: The operand is selected with a pick device.

Prerequisite Devices: A pick device.

(c) Operand Selection by Label Type-In

Summary: The user types in the label of an operand.

Prerequisite Devices: Alphanumeric keyboard.

Description: The user selects the desired operand by typing in the label of the operand. The technique is very similar to command type-in except the label of the operand is being entered rather than the command. The label would typically be displayed along with each potential operand. For example, we might have Figure 4.6 which shows two lines and their labels, which in this case are the integers 4 and 16 (alphanumeric labels can of course be used). To delete line 4, the delete command would be entered, followed by the number 4.

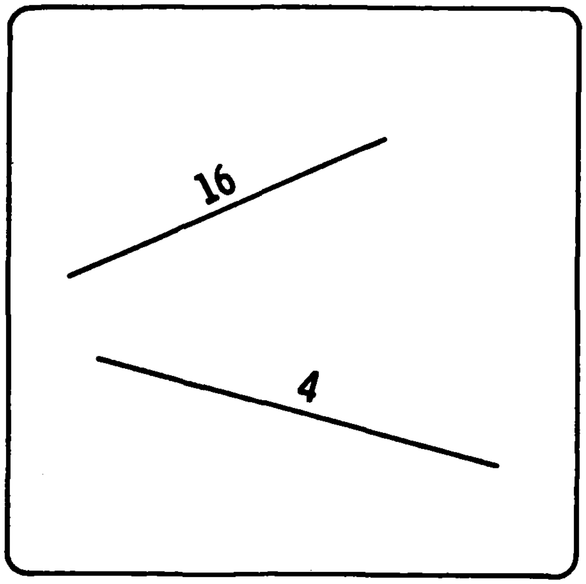


Figure 4.6. Labeled lines.

(d) Operand Selection by Time Scan

Summary: The system successively increases the intensity of each displayed entity for a short period of time. The user activates a button to indicate the desired item as it brightens.

Prerequisite Devices: A group of buttons, refresh display.

Decription: The system displays a screen of possible choices. Each displayed entity is then successively increased in intensity for a short period of time. When the desired entity brightens, the user activates a button to indicate the selection.

More than one button is needed for the technique. Usually several entities are likely to have brightened during the brief moment between the desired entity's brightening and the button activation. Thus another button is used to reverse the brightening sequence, one at a time. When the correct entity is again brightened, the user activates a third button to actually make the selection.

This technique is especially useful if items are close together on the screen, making it difficult for the user to pick with the lightpen or the cursor. An example of a successful application of the technique is to pick a single atom from a large molecule.

4.1.3. Discussion of Selection Techniques

Table 4.1 shows estimated rankings of selection techniques, based on our readings, the experiments, and our experiences. The ratings are relative, and are only our best estimate. They are far from sacrosanct

The techniques involving selection from the screen using a pointing device have been relatively extensively studied, as indicated in Figure 3.1. The references [CARD78], [EARL65], [ENGL67], [FIEL78], [GOOD75], and [MORR68] indicate the techniques studied in each of these six experiments. One sees from Figure 3.1 that many of the techniques have not been studied at all. The [CARD78] experiment found the mouse superior to velocity joystick and cursor control keys. Similarly, [ENGL67] finds that for experienced users the mouse is superior to a light pen or absolute joystick, and that for inexperienced users the light pen is marginally better than the mouse, and superior to both the absolute and velocity-controlled joystick. These two experiments suggest that neither the joystick nor the cursor control keys are as satisfactory as the mouse or light pen. The tablet used in [ENGL67] was mechanically coupled and not all typical of contemporary tablets: we thus make no conclusions about tablets. This is confirmed in [GOOD75], which finds the light pen superior to cursor control keys (albeit of an awkward, unrealistic type).

In [MEHR72], the experiment finds that the trackball is superior to several different types of joysticks in moving a cursor to a target (which is to be selected). Based on all these results, we are inclined to dismiss the joystick as a selection device.

Comparing name type-in on a keyboard versus selection from a menu on the screen, we have contradictory results. [FIEL78] finds the keyboard and selection from a menu using a trackball equal in speed (although menu selection was more accurate, as typing errors were precluded). By contrast, [EARL65] finds light pen picking faster (as well as more accurate) than keyboard type-in. A crucial additional factor to consider is the size of the menu. In the case of [EARL65] it was small (up to 18 items) while for [FIEL78] it was large (up to 40 items), so search time would naturally work to the disadvantage of the menu. Also, in both experiments the subjects already knew which menu selection they were seeking; thus the menu was not serving one of its useful roles - that of a memory aid to indicate the set of available choices.

In [FIEL78] and[EARL65], the experiments compare menus to keyboard type-in in environments in which the <u>name</u> of the desired selection is given to the operator, and the operator must locate <u>where</u> the selection is located on the menu. If the selection were being made from a displayed drawing with which the user was interacting, different results would be expected. The user may already know <u>where</u> an item of interest was located, and could thus quickly point at it. Remembering (or creating) a <u>name</u> to be typed would take rather longer.

Just as with the positioning task, therefore, we see a difference between techniques based upon the form of the knowledge the user brings to the task. In the positioning case, the distinction was between

Table 4.1
Comparison of Selection Techniques

	Ergonomic Measures								
Techniques	Cognitive Load	Percept-ual Load	Motor Load	Visual Acquis-ition	Motor Acquis-ition	Ease of Learning	Fatigue	Error Proneness	Feedback Type
Light pen.	L	L	M	L	M	L	M	L	NA
Touch panel.	L	L	L	L	L	L	L	L	NA
Indirect, with cursor match.			[See Quantifying]						NA
With character string name.			[See Text Entry]						NA
Time scan with programmed function keyboard.	H	H	M	H	M	M	H	H	NA
Time scan with alpha-numeric keyboard.	H	H	M	H	H	M	H	H	NA
With uniquely labelled button using programmed function key.	L	L	L	M	M	L	L	L	NA
With uniquely labelled button using soft keys.	L	L	L	M	M	L	L	L	NA
With unique movement using tablet & stylus	H	M	M	H	M	H	H	M	NA

knowing the position as a place on the display or knowing the coordinate values. In the selection case, the distinction is between knowing the selection as a place on the display or as a name. The experiments deal only with the latter case, in which the name is known and the location in the menu is not. This spatial versus linguistic form of knowledge is fundamental to the selection of techniques.

There are very persuasive anecdotal stories about menu - light pen systems in the hands of experienced users who, through practice, know the position of a desired menu item. Users are reported (by reliable observers) to have their light pens poised to make a selection, even before the menu actually appears on the screen. This is a case where computer delays in presenting the menu actually slow down the interaction. This would not happen if the computer supporting the application were not time shared.

4.2. Positioning Techniques

The positioning task involves specifying a position in application coordinates. The requirements of the task, determined by the application, are dimensionality, resolution, and closed-loop or open-loop feedback. Before discussing specific interaction techniques for positioning, several general issues which transcend specific techniques need to be discussed, because they are relevant to some or all of the techniques. These are some of the parameters of interaction techniques.

When a positioning task is performed, several issues, independent of the particular technique or device used, are involved. They are as follows:

1) Coordinate System

The user of an interactive graphic system is typically aware of up to three coordinate systems: the application coordinate system, in which the computer maintains coordinates, the screen coordinate system, in which the user views an image, and the positioning device coordinate system, in which the user moves a tablet, joystick, mouse, or other device. At issue is the relationship (i.e., geometric transformation) between these three coordinate systems. This is important because it determines the relation between user hand movements and graphic object movements on the screen. Empirical observations [BRIT78] suggest there should be no rotation in the positioning device to screen transformation. This means a movement of the hand to the right should cause the screen cursor or other graphic object also to move to the right. This should be true even if the viewing transformation from world to screen coordinates does include a rotation.

2) Cursor Form Management and Visual Aids

For those positioning techniques involving movement of a displayed screen cursor to a desired location, the user must first

find the screen cursor. Studies have shown that the more alike the background items and the target are, the longer it will take to acquire the target. Thus there are several things to be noted when choosing the form of the screen cursor on a display. On an alphanumeric display we should choose a cursor form that is distinctively different than any of the alphabets, numerals, or special characters. Hence, any cursor such as a box or diamond shaped form will be a much better choice than a cursor such as an underline or a cross form. For other graphics applications, it is important to choose a cursor form that is different from the commonly used graphics forms. The cursor can also be differentiated from the rest of the displayed information by intensity, color, or blink.

Positioning time can be reduced by using proper cursor form and visual aids. A box-shaped cursor blinking at 3HZ was found to be the optimal form and rate to be effectively searched for and moved on an alphanumeric display. Other forms or rates took longer to visually acquire (that is, "locate")[VART65].

An important visual aid for many positioning tasks is a grid superimposed (perhaps at low intensity) on the drawing, to help in aligning positions or objects. A grid (or coordinate axis along the edges of the display) is also helpful if the user must convert a position on the screen into numeric coordinates for keyboard entry.

3) Control/Display Ratio

The control/display (C/D) ratio is the ratio of the control (the hand movement of the operator, the stick movement of the joystick, etc.) to that of the moving element on the display (target, screen cursor, etc.). It has been shown that the C/D ratio of a control device is critical to the operator's performance using that device [JENK49, JENK54, JENK50]. For linear controls, say a tablet with a stylus, the C/D ratio is defined by the formula:

$$C/D = \text{movement of hand}/\text{movement of cursor}$$

For rotary controls, such as the track ball and the joystick, the C/D ratio is defined as:

$$C/D = \frac{(\text{fraction of circle movement})*(\text{diameter of circle})}{(\text{movement of cursor})}$$

$$= (A \,/\, 360) * (2 * pi * L) \,/\, (\text{movement of cursor})$$

where A = the degrees of travel of the control device (in degrees) and L = the length of the control device.

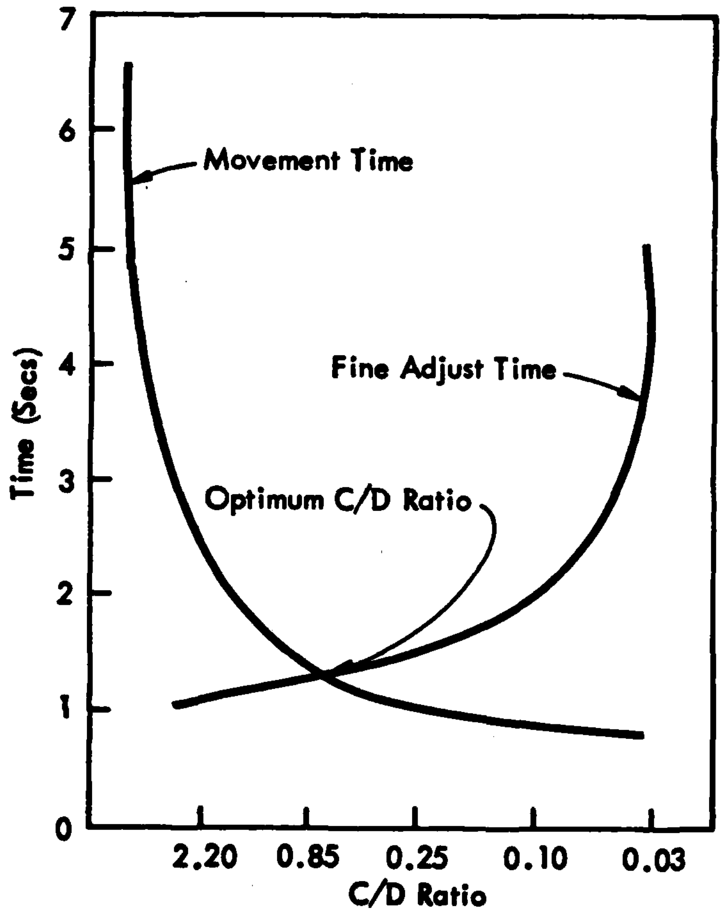


Figure 4.7. The effect of C/D ratio on movement time and adjustment time. (Adapted from Jenkins and Connor [JENK49].)

Generally speaking, a low ratio is good for fast movement and a high ratio is good for fine adjustment accuracy. Figure 4.7 illustrates the effect of C/D ratio on movement time and adjustment time. The optimum C/D ratio is that which produces the least total time to use a control. Experience (not experiments) suggests that for tablets, the workable C/D ratio ranges from 1 to 0.5. For knobs and dials, the optimum C/D ratio usually falls between 0.2 and 0.8. For example, a 5" joystick with 90 degrees of movement has about 8" of travel. Used with a typical 12" x 12" screen, the C/D ratio is about 0.67. However, using a joystick requires grosser motor movements, making the device difficult to use for fine adjustments. Note that the C/D ratio is just the scale factor which relates the positioning device coordinates to screen coordinates, as described in item 1 above.

Inherent in graphics applications is the type of feedback provided. A continuous translation technique, whether it is direct, such as using the light pen to directly show a position, or indirect, using a locator

to indirectly show a position by moving a screen cursor, implies closed loop dynamic feedback as either the cursor or the object of interest moves across the display. This allows the user to move the screen cursor through a succession of "trial" positions until the results are satisfactory. Therefore this continuous feedback is appropriate when the user knows where on the screen the position of interest is but does not know the coordinates of the position.

Conversely, discrete feedback is appropriate when the user knows the coordinates, but not the desired positions. The coordinates would be typed, and the object or screen cursor repositioned appropriately.

4.2.1. Continuous Translation

(a) Continuous Indirect Translation, with Locator Devices

Summary: A locator is a device whose position is used to indicate a location on the screen. The movement of a locator device is directly mapped into the movement of a dis~layed object. Examples are the tablet, the mouse, the trackball, the joystick and the cursor control keys with auto-repeat.

Prerequisite Devices: A positioning device which indicates a location. Prototype locators include the tablet, the mouse, the trackball, and the joystick. Also required is a refresh display device.

Description: Locators have dimensionality. Depending on their design, locators give positions in one, two, or three dimensions. Some can even locate positions in up to six or seven dimensions.

There are two kinds of locators, the absolute and the relative. locators. The absolute locator indicates position with respect to the absolute origin of its control movement. Hence, the range of a locator is limited by its physical size. The tablet is a typical absolute locator.

The relative locator, in contrast, indicates position relative to its control movement. The mouse, the track ball and the velocity-control joystick are some of the relative locators. For example, if the mouse is used to move a display cursor, the user rolls the device over a surface, picks the mouse up, and rolls again. This action causes the cursor to move rapidly across the screen independent of the surface area available for the mouse to roll on. Thus, the relative locator is not limited by the physical space. The absolute locator, on the other hand, has a more permanent hand-eye relationship.

Very often a joystick is used as a physical locator. However, the joystick, because of its inherently large control/display (C/D) ratio, can be difficult to use. A 5- or 10-fold amplification of hand movement usually occurs while positioning the cursor. The amplified hand movements can become quite jerky and don't allow for accurate positioning.

Thus the joystick is more suited for controlling the velocity of the display cursor's movement, rather than indicating the absolute position.

(b) Continuous Indirect Translation, with Velocity Controlled Joystick

Summary: A return-to-zero joystick is used to control the velocity of a cursor. Zero displacement of the joystick corresponds to zero velocity.

Prerequisite Devices: A positioning device with automatic return to zero. The spring-return joystick and isometric joystick are members of this device class.

Description: A cursor on the screen is continuously repositioned. The positioning is velocity-controlled, based on the joystick values. The position at time t is given by a starting position plus the integral, up to time t, of the velocity values entered from the joystick.

Any initial position can be used. Joystick movement causes the cursor to move. When the user releases the joystick, the cursor stops moving. The relationship between the joystick displacement and the velocities along the x and y axes is usually linear, readily allowing full-screen movement at maximum velocity in less than five seconds. Figure 4.8 shows such a relationship, as well as the relationship when the control has a signed quadratic form. The lower sensitivity in the low displacement range helps fine motor control.

Joysticks with a rotatable center shaft can be used for 3D positioning tasks; otherwise, they are limited to 2D.

(c) Continuous Indirect Translation, with Up-Down-Left-Right Keys

Summary: The desired location of a graphic object is controlled by using step keys to move the object up, down, left, right, in, or out.

Prerequisite Devices: A set of four or six keys on an alphanumeric keyboard, a programmed function keyboard, or other special key-input devices.

Description: The user indicates the desired location of the display cursor by depressing a set of keys which are assigned to control the cursor movements (up, down, left, right for 2D applications, plus in, out for 3D applications). A continual key depression causes the cursor to move in a rapid continuous motion, while a quick key depression causes the cursor to move a unit of display resolution. Rapid positioning is facilitated by allowing the cursor's speed to accelerate as long as the key is down. When the key is released, the cursor stops.

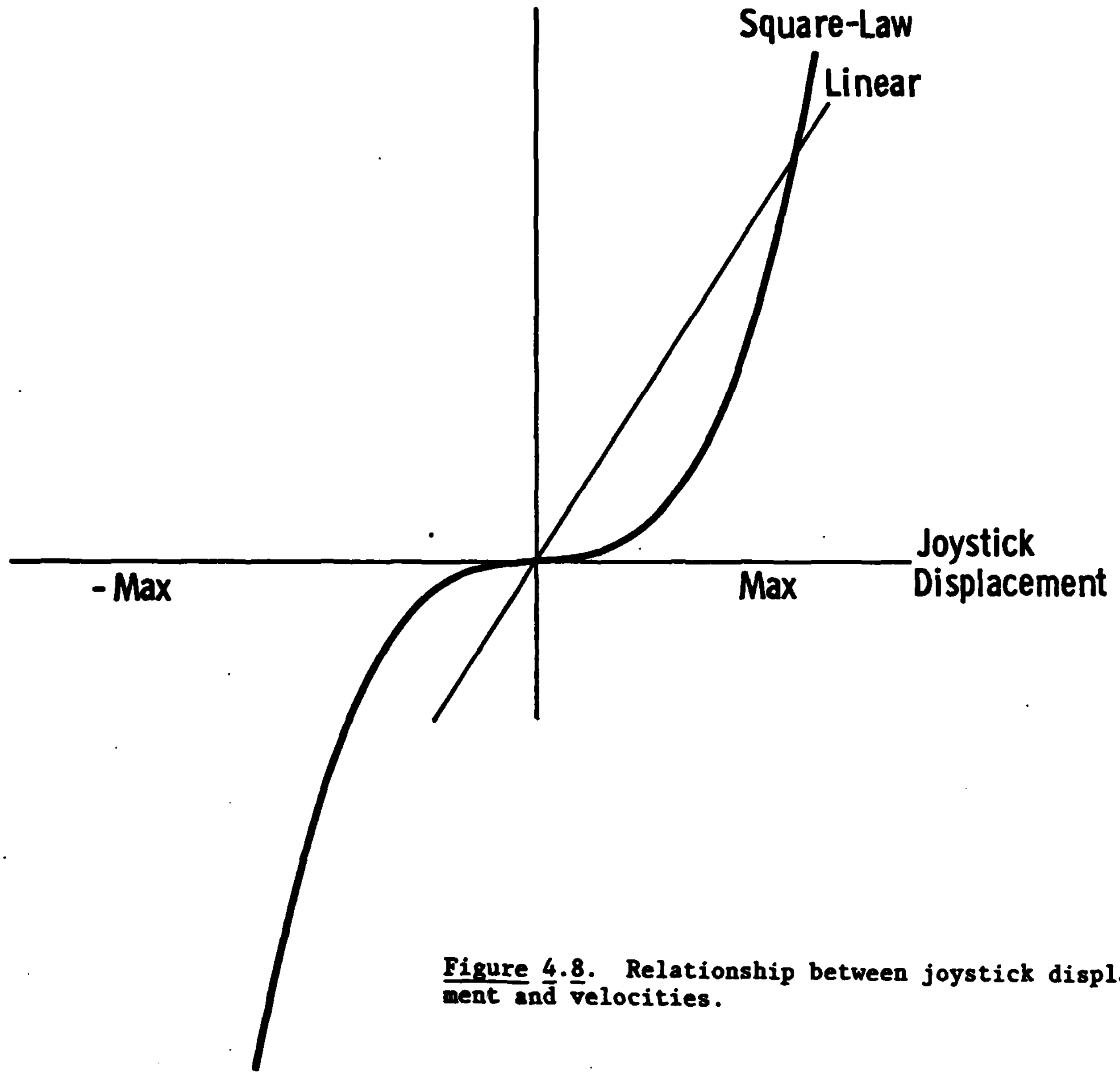


Figure 4.8. Relationship between joystick displacement and velocities.

Figure 4.8. Relationship between joystick displacement and velocities.

(d) Continuous Direct Translation, with Light Pen Tracking

Summary: Tracking is performed using a small cross (called the tracking cross) pointed at with a light pen. As the pen moves to a new position, the tracking cross follows.

Prerequisite Devices: Light pen, vector refresh display.

Description: To start tracking, the cross must be on the display.

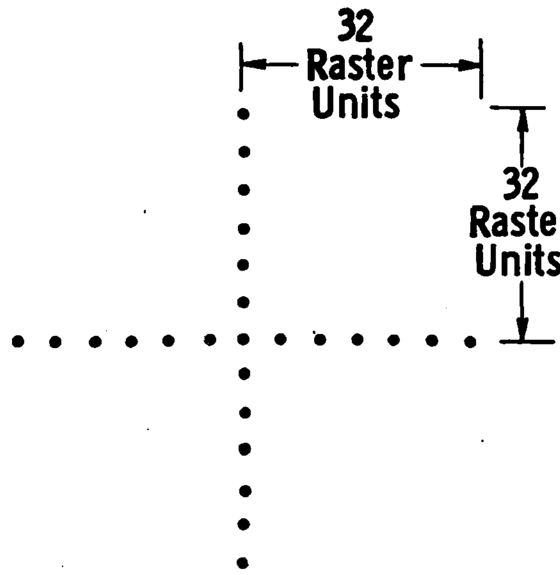


Figure 4.9. A tracking cross.

Figure 4.9 shows a 64 x 64 display unit tracking cross. The user points at it with the light pen. As the pen moves, the cross follows the motions of the pen. If tracking is "lost" because the pen is moved too fast and the tracking algorithm of the system cannot follow the pen's motion, the user may resume tracking by moving the pen back to the cross. The use of a light pen for positioning on a raster display is described as "Direct, with locator device".

In most interactive dialogues, pen tracking is terminated by an explicit user action such as activating a switch to indicate that the cross is at its desired location. This explicit action is not really necessary; the position can be implicitly accepted when the user proceeds to enter the next command.

Pen tracking is a 2D technique. No data is known concerning the resolution it can achieve on a display screen - one part in 1000 is surely the best that can be done. By showing an enlarged view on the screen, this resolution can be effectively made much greater in application coordinates.

(e) Continuous Direct Translation, with Continuous Search for Light Pen

Summary: A light pen is pointed at the screen. A raster scan of the screen is used to find the pen's position.

Prerequisite Devices: Light pen, refresh display.

Description: Continuous search for the light pen is a variation of the tracking technique. To find the position of the light pen,

a raster scan (using dots, letters or lines) is displayed for each refresh cycle. The user points at the screen with the light pen. When a displayed entity is seen by the pen, the position of the pen is known. After acquiring the initial position of the pen, there are now two ways of continually knowing the new position of the pen as the pen moves. The first method is to display a tracking cross beneath the pen and start tracking. The raster scan will only be used again if tracking is lost. The other method uses the raster scan every few refresh cycles to search for the light pen. The first method is preferred over the latter; user attention is not distracted by the continuing raster scan display, which at least partially obliterates the displayed information.

On the other hand, the raster scan is useful for initially acquiring the light pen position: the computer searches for the pen, so the user need not visually search for the tracking cross.

4.2.2. Discrete Translation

(a) Discrete Translation by Position Type-In

Summary: User indicates a position on the screen by typing in coordinate values.

Prerequisite Devices: Alphanumeric keyboard.

Description: To indicate a position on the display screen, the coordinates of the location are typed in via a keyboard. A cursor is then displayed at the user-specified location to provide visual feedback. Unlike a continuous translation technique which continuously updates the position of the display cursor, a discrete translation type-in technique changes the location of the display cursor only when a new position is entered. One disadvantage of this technique is the lack of continuous visual feedback to give the user a continuance of changes. Another disadvantage is the cognitive load imposed on the user.

This technique can have arbitrarily high resolution and dimensionality, limited only by the amount of information the user is willing to type. This technique preserves tactile continuity if the action language is keyboard-oriented.

4.2.3. Discussion of Positioning Techniques

The characteristics of these techniques are summarized in the following table. Notice that by scaling up the displayed image, any of the techniques can be used to achieve any desired resolution. On the other hand, creating the scaled-up image can be slow with some hardware configurations (but essentially instantaneous on others), so resolution can be a concern.

Table 4.2
<u>Comparison of Positioning Techniques</u>

Techniques	Ergonomic Measures								
	Cognitive Load	Perceptual Load	Motor Load	Visual Acquisition	Motor Acquisition	Ease of Learning	Fatigue	Error Proneness	Feedback Type
Direct, with touch panel.	L	L	L	L	L	L	L	L	D
Indirect, with tablet.	M	M	M	M	M	M	L	L	C
Indirect, with mouse.	M	M	M	M	M	M	L	M	C
Indirect, with absolute joystick.	M	M	M	M	M	M	L	M	C
Indirect, with velocity controlled joystick.	M	M	M	M	M	M	L	H	C
Indirect, with track-ball.	M	M	M	L	M	M	L	M	C
Indirect, with cursor controlled keys & auto-repeat.	H	H	M	H	M	M	L	M	C
Indirect, with up-down-left-right arrow keys.	H	H	M	H	M	M	L	M	C

Choice of a continuous or discrete feedback technique, based on whether the user knows where the position is on the display or the coordinates of the position, is critical. The wrong choice means a heavy cognitive load in converting from a spatial representation to a text-string representation, or vice versa.

The direct versus indirect positioning technique choice hinges on questions of fatigue and hand-eye coordination. Direct techniques minimize all but motor effort, which is high because the arm must normally be raised to the screen. Indirect techniques require more learning of hand-eye coordination.

Fatigue in direct methods has been much-discussed, and is commonly assumed to be a problem. However, there are anecdotal reports of draftsmen and designers using light pens for hours without problems. We have found no germane experiments.

Learning of hand-eye coordination for indirect methods, the other common concern, is really not a major issue. CARD78, which studies the mouse and joystick for selection, shows improvement, with repeated use, in both error rate and selection times. However, even the performance of novices was quite good. Positioning time for a mouse decreased with practice from 2.2 to 1.3 seconds. For a joystick it decreased from 2.2 to 1.4. For several uses of discrete positioning the time decreased from more than 3 seconds to about 2.2 seconds. Note, though, that when compared to a direct technique (the light pen) for selection in ENGL67, the pen was slightly faster (though less accurate) for novices. Again, the difference was small.

There are no "pure" positioning experiments; the above-mentioned experiments all concern selection. We believe the results, which are discussed in detail in the selection section, can be generalized to positioning.

4.3. Orienting Techniques

The orienting task involves specifying an orientation instead of a position in a coordinate system. The requirements of the task, again determined by the application, are the degrees of freedom, the type of feedback (closed-loop or open-loop), and the resolution desired.

Interaction devices used are the quantifiers, the locators used for positioning, and the alphanumeric keyboard, depending on the task requirements.

As with positioning, there are a number of general issues which concern orienting techniques. They are as follows:

1) Center of Rotation

The center of rotation of an object might be the origin of world coordinates, the center of the object, or any arbitrary user-specified position. In any case, the user must know where the center of rotation is located. Intuitively, the most convenient center of rotation is the center of the object being oriented. If the object spans the entire screen, then the center of the screen becomes the center of rotation.

2) Visual Aids

Especially in 3D orientation tasks, the user often has difficulty in knowing exactly how the displayed object is currently oriented. Display of a gnomen can aid in this--a commonly-used gnomen is just a set of axes on which the positive and negative x, y, and z axes are labelled. The axes are displayed with the same orientation as is the object of interest.

3) Coordinate Systems

The discussion of this issue with respect to positioning devices is also relevant to orientation.

4.3.1. Continuous Orientation

(a) Indirect Continuous Orientation, with Locator Devices

Summary: The desired orientation is directly controlled by a quantifier or locator.

Prerequisite Devices: Continuous quantifier or physical locator. Typical devices used are the tablet, the absolute-controlled 3D joystick, and dials.

Description: To rotate a 2D object, the user specifies the angle of orientation by using a continuous quantifier or one axis of a locator. The device is read continuously, and its value mapped to the new orientation of the displayed object. There is a one-to-one correspondence between the movement of the hand with the device and the movement of the object on the screen. The definite advantage of the technique is the preservation of hand-eye coordination. Of course use of a locator means that linear movement of the hand is converted to rotational movement.

For 3D applications, quantifiers or locators can be used to rotate a displayed object by specifying roll/pitch/yaw or direction cosines.

(b) Indirect Continuous Orientation, with Velocity Controlled Joystick

Summary: The velocity of orientation change is controlled by the use of a return-to-zero joystick. Zero displacement of the joystick corresponds to zero velocity, and hence no change in orientation.

Prerequisite Devices: Any positioning device with automatic return to zero. Typical devices of this class are the spring-return and the isometric joysticks.

Description: The diplayed object is continuously rotated. The technique is very similar to the direct-controlled techniques for continuous translation, except that it is the angle of orientation which is velocity-controlled, rather than the distance of translation, based on the values from the device. The relation between angular displacement(s) and the input value(s) is analogous to that for velocity-controlled positioning. Moving the device rotates the object. When the device is released, the object stops rotating.

Unlike the direct-controlled technique, this technique does not preserve this hand-eye coordination. The real advantage of this technique is that a large change of orientation can be obtained by small hand movements.

4.3.2. Discrete Orientation

(a) Discrete Orientation by Angle Type-In

Summary: The user types in values to define an orientation.

Prerequisite devices: Alphanumeric Keyboard.

Description: An orientation is typed at the keyboard, either as angles, direction cosines, pitch-roll-yaw, or some other form. The new orientation is shown. If wrong, the type-in must be repeated. However, if the action language is keyboard-oriented, the technique preserves tactile continuity.

Rotation also involves implicit or explicit specification of the center of rotation. It can be the center of the object, or of any arbitrary user-specified position. In the latter case, the center of rotation would be specified using a positioning technique.

4.3.3. Discussion of Orienting Techniques

Characteristics of the technique are given in the following table. All of these techniques are indirect - there is no practical analogue to the touch panel for orientation. (See [HERO78] for the description of an experimental direct orientation device.) Thus the fatigue question does not arise. The hand-eye coordination issue is germane, but no data are available. Naturally, clockwise hand movement should result in clockwise rotation of an object on the screen. Conversely, in a simulation environment, a clockwise hand movement would cause the screen display to rotate counter-clockwise. The continuous versus discrete

Table 4.3
Comparison of Orienting Techniques

	Ergonomic Measures								
Techniques	Cognitive Load	Perceptual Load	Motor Load	Visual Acquisition	Motor Acquisition	Ease of Learning	Fatigue	Error Proneness	Feedback Type
Indirect, with joystick (absolute).	L	L	L	L	L	L	L	L	C
Indirect, with joystick (velocity controlled).	M	L	L	L	L	L	L	M	C
Numeric character strings.	[See Text Entry]								

feedback issue, discussed with positioning, is equally relevant for orienting.

4.4. Pathing Techniques

The pathing task involves specification of a series of locations or orientations, evolving in time and space. Pathing is always continuous, and closed loop. Its requirements are: the maximum number of positions or orientations along the path, the interval of sampling and whether it is time based or distance based, the dimensionality, the resolution of individual samples, and whether it is a positioning or orienting path or both.

Any positioning or orienting device can be used for pathing, provided only that the system is capable of supporting closed-loop operation. Furthermore, the pathing technique is concerned with all of the same issues as the corresponding positioning and orienting techniques.

In addition, pathing has the issue of interval selection. When the sampling interval is distance-based, the smoothness of the path echo is controlled. Each sample position may be a vertex on an echo, and when vertices are separated by a uniform distance, the visual effect is a uniform smoothness over the duration of the historical path. When sampling is time-based, samples will be separated by larger distances when the path is changing rapidly, and shorter distances when the path is changing slowly. The effect on a line-drawn echo is greater smoothness and faithfulness to shape when the device is moved slowly and, presumably, with more deliberation. When the echo is a scene change, this alternative is closest to the effect of a motion picture. Thus, one chooses between distance-sampling and time-sampling depending on whether smoothness and uniformity of faithfulness of the historical path is important, or whether the perception of smoothness of motion of the echo image is important.

Pathing also has the issue of echo forms. By echo, we mean the question of how the variation of position or orientation is made visually evident to the user. The echo may be a continuously wavy line which lays down the history of positions followed by the path. The echo may be only a cursor or gnomen indicating the current endpoint or end-orientation of the path, or the echo may be a modification of the viewing or image transformation of some object or display. In the latter case the effect is one of looking through the window of a vehicle whose "path" is being controlled, or of "flying" an object on the screen under the control of a device.

A final issue is that techniques differ according to how the echo is "smoothed". An echo which lays down the history of the path as an image may simply join the sample vertices by straight lines, may not join them at all (leaving a series of dots), or may join the vertices by one or another spline technique. (A spline is a continuous curve which has continuous first, and sometimes higher, derivatives. That is, they

have no cusps or fold-points.) Orientation of an image may be similarly smoother giving the effect of continuous motion even when the samples are widely separated in time.

4.4.1. Discussion of Pathing

Because pathing differs from positioning only in the nature of the data returned and not in performance characteristics, the discussions (Sections 4.2.3 and 4.3.3) are appropriate to pathing as well.

Intuition suggests that good hand-eye coordination is perhaps more important in pathing than in positioning or orienting. Furthermore, continuous feedback techniques will be almost exclusively used, even though occasionally an application may deal with a selection of a pre-plotted (discrete) path.

Experimental data are similarly dependent on experiments for positioning The experiments by Irving [IRVI76] compared devices in the special context of pathing, but they were inconclusive.

4.5. Quantifying Techniques

The quantifying task involves specifying a value or number, within a specified range of numbers. Several issues are germane to all quantifying techniques and will be discussed briefly here. They are similar to some of the issues discussed in Section 4.2.

1) Range Specification

It is important that the range of the number to be specified is reasonably chosen. Choice of too large a range, for many techniques, can limit useful resolution and cause control/display ration to be excessively high. Unbounded techniques may not have this problem, if control/display ratio is well chosen.

2) Control/Display Ratio

As with positioning, the amount of physical movement corresponding to any change of the selected number is critical to performance. Again, low ratios will be good for fast change while high ratios will be good for fine adjustment accuracy (see Sec. 4.2). Several techniques below exhibit a variable ratio, initially favoring low ratio and finishing the action with a high ratio.

3) Echo Form

Use of a scale versus presentation of a number can be critical to performance.

4.5.1. Continuous Quantifying

(a) Continuous Quantifying using Physical Devices

Summary: Quantifying can be directly accomplished either by using a slide, a dial, or a strain gauge device. (Mechanisms for locating are also generally applicable, but they appear not to be commercially available--e.g., tablet, resistive surface, strain, servo, etc.)

Prerequisite Devices: A dial (rotational potentiometer) or slide (linear potentiometer).

Description: Quantifying a value may be accomplished in either a discrete or continuous fashion. In the continuous mode, one may use a bounded dial, an unbounded dial, or a slide. A bounded dial is similar to the volume control on a radio--turning the dial far enough in one direction, one encounters a stop past which the dial cannot further be turned. This type of device indicates an absolute quantity.

An unbounded dial resembles the bounded dial except that there are no stops. One can turn the dial an "unbounded" distance in either direction. An unbounded dial specifies a relative quantity. Using some sort of echo enables the user to determine what value is currently being specified. Turning the dial in one direction increments the quantity, turning the dial in the other direction decrements the quantity.

(b) Continuous Quantifying by Scale Drag

Summary: Quantifying is performed by pointing a light pen at a scale. The pen is initially pointed to the current indicator position of the scale and then moved along the scale until the desired value is reached.

Prerequisite Devices: Light pen, refresh display.

Description: To quantify using the scale drag technique, the user initializes the screen, causing the scale to appear. The user then points to the "zero" or least-valued end of the scale with the light pen, and then moves the light pen along the scale to the desired value. When the desired value is selected, the light pen is removed from the screen, or a button, preferably on the light pen, is pressed. A highlighted line or pointer may be used to indicate the length on the scale that has been selected, or a numeric echo may appear (preferably at a standard position on the screen).

(c) Continuous Quantifying using Locator Value

Summary: A locator is moved, causing its current x-coordinate or y-coordinate to position a pointer on a scale. (This movement may or may not be proportional to the movement of the pointer on the scale; however, the movements should be coordinated.) The position of the cursor indicates the value to be specified. A digital value may also be displayed.

Prerequisite Devices: Locator.

Description: The screen is initialized with the locator on the scale. The user moves the locator along the x-axis or the y-axis, specifing a value on the scale. Note that this technique may be used like a scale drag. The screen is initialized with the locator on the scale. By moving the locator along the scale, a quantity (from the initial indicator position to the current indicator position) may be specified.

(d) Continuous Quantifying using Dial with Echo

Summary: A dial is used to increment or decrement a digital echo.

Prerequisite Devices: Dial (optional fine tuning), refresh display.

Description: The user turns a dial. On the screen (preferably at a standard position), a digital representation of the quantity changes. This change of the represented value may correspond to either a large or small amount of turn in the dial, depending on whether or not fine tuning of the number is desired. Some method of fine tuning may be included.

(e) Continuous Quantifying using Dial with Scale

Summary: A dial is used to move the cursor or other indicator along a scale.

Prerequisite Devices: Dial, refresh display.

Description: The screen is initialized with a scale and a cursor or other indicator. As the user turns a dial, the cursor or other form of pointer moves along a scale on the screen. A method of controlling the velocity at which the indicator moves may be included.

(f) Continuous Quantifying using Light Handle

Summary: A tracking cross is moved in a work area with a light pen.

Prerequisite Devices: Light pen, refresh display.

Description: A tracking cross is located in a work area composed of at least two adjacent rectangles. A displayed value is associated with the location of the tracking cross in the work area. Upward movements of the cross cause the value to increase; downward, decrease. Movements in the left part of the work area cause larger changes than movements in the right part. Horizontal movements have no effect on the value. All vertical movements, except those in the right-hand part, cause changes proportional to the square of the change in Y. In the right-hand part, the number changes are proportional to the change in Y, so that a "fine tuning" mechanism exists. See [NEWM68] for a detailed discussion.

A light pen is usually used to move the cross with a regular pen tracking algorithm.

(g) Continuous Quantifying using Locator - Ratchet Value

Summary: In a scale drag (or locator value) setting, movements of the cursor which would normally cause the displayed value to decrease instead cause the scale to shift.

Prerequisite Devices: Light pen.

Description: A scale is present on the screen. The user points to the least-valued end of the scale with a light pen. The user then moves the pen along the scale which causes the displayed value to increase. When the user moves the pen back along the scale, instead of the value decreasing, the whole scale shifts to allow larger values to be specified.

As in the scale drag case, some action, either explicit or implicit (for example, the entering of a new command) must signal the selection of a value.

(h) Continuous Quantifying using Simulated Stop Watch

Summary: The user holds a button down which starts a displayed number to begin to increase at a constant rate. When the desired number appears, the button is released.

Prerequisite Devices: Button, dial(optional), refresh display.

Description: The user pushes a button which activates a "digital watch" effect. A number is displayed which begins to change at a constant rate. This rate may be optionally regulated by a dial; turning the dial causes the rate to either accelerate or decelerate. Before the desired value is reached, quick jabs of the button may be used to cause smaller changes in the number. When the desired value is displayed, the button is released al-

Table 4.4

Comparison of Quantifying Techniques

	Ergonomic Measures								
Techniques	Cognitive Load	Percept- ual Load	Motor Load	Visual Acquis- ition	Motor Acquis- ition	Ease of Learning	Fatigue	Error Proneness	Feedback Type
Direct, with rotary Potentiometer.	M	L	M	M	M	L	L	L	C
Direct, with linear potentionmeter.	M	L	M	M	M	L	L	L	C
Numeric character string.				[See Text Entry]					
Scale drag with one axis of tablet.	M	M	M	M	M	L	M	L	C
Scale drag with one axis of mouse.	M	M	M	M	M	L	M	M	C

together, and another action, for example, pressing another button, signals the designation of the displayed number. A "back-up" button can also be provided, to be used if the desired value is initially passed over.

4.5.2. Discrete Quantifying

(a) Discrete Quantifying by Type-In

Summary: The user types in the desired quantity at the keyboard.

Prerequisite Devices: Keyboard.

Description: The user types in the desired number at the keyboard.

4.5.3. Discussion of Quantifying Techniques

The characteristics of these techniques are summarized in Table 4.4. We are aware of no experiments relating to quantifying tasks or techniques.

4.6. Text Entry Techniques

A text entry technique involves expressing information in a form involving a string or block of "characters" selected from a character set which is predefined for the discourse. Text is entered from keyboards, which are described below.

An important distinction must be noted between text and selection. In text, each character individually causes no action, but collectively the string acts as a single entity. Therefore, each key has the same meaning, regardless of the situation. In selection, however, each key (i.e., selection) can cause an action, and the meaning of the key may change depending on the situation in which the key was depressed. Notice that this definition of keyboard does not specify what the keyboard looks like, how many keys it has, nor what types of actions are initiated by strings of keystrokes. In fof act, keyboards other than alphanumeric keyboards are possible. For example, one might use a steno keyboard which enters strings of syllables, or a piano keyboard where meaning is attached to "chords." In any keyboard, however, some special convention is needed to signal the end of the text. On an alphanumeric keyboard, a "return" key usually serves this purpose.

(a) Text Entry by Voice Recognition

Summary: Letters are spoken and recognized by a voice recognizer.

Prerequisite Devices: Voice recognizer.

Description: A keyboard may be implemented by using a voice recognition device. Each letter is spoken, and separated by 0.1 to 0.2 seconds of silence. Commonly-used words could also be recognized as a way to speed-up the input process. Recognizing an unlimited vocabulary, on the other hand, is in the distant future.

(b) Text Entry by Stroked Character Recognition

Summary: Letters are printed and recognized.

Prerequisite Devices: Continuous positioning device with stylus.

Description: The user prints the text, usually with a tablet and stylus. The computer then attempts to break the "text" into strokes from which letters may be recognized. For instance, the capital letter "A" consists of three strokes--typically, two downward strokes and a horizontal stroke. Recognition errors are possible, and some convenient correction method is essential.

(c) Text Entry by Menu Selection

Summary: Letters are selected from a menu.

Prerequisite Devices: Selection device.

Description: A series of letters, syllables, or other basic units is displayed as a menu. The user then inputs text by choosing letters from the menu.

4.6.1. Discussion of Text Entry

For massive input of text, there is no substitute for a skilled typist working with a traditional keyboard, save automatic scanners. Figure 4.10, adapted from [DEVO67], shows experimentally-determined input rates using a variety of techniques. Speech input, not shown on the chart, is especially attractive for applications where the hands need to be kept free for other purposes, such as handling paperwork.

The hunt-and-peck typist is limited by the perceptual task of finding a key and the ensuing motor task of moving to and striking it, while the trained typist has only the motor task of striking the key, preceded sometimes by a slight hand or finger movement to reach the key.

The characteristics of the techniques for text entry are summarized in Table 4.5.

None of the techniques discussed pose any real limit on character set size, so long as western alphabets are considered.

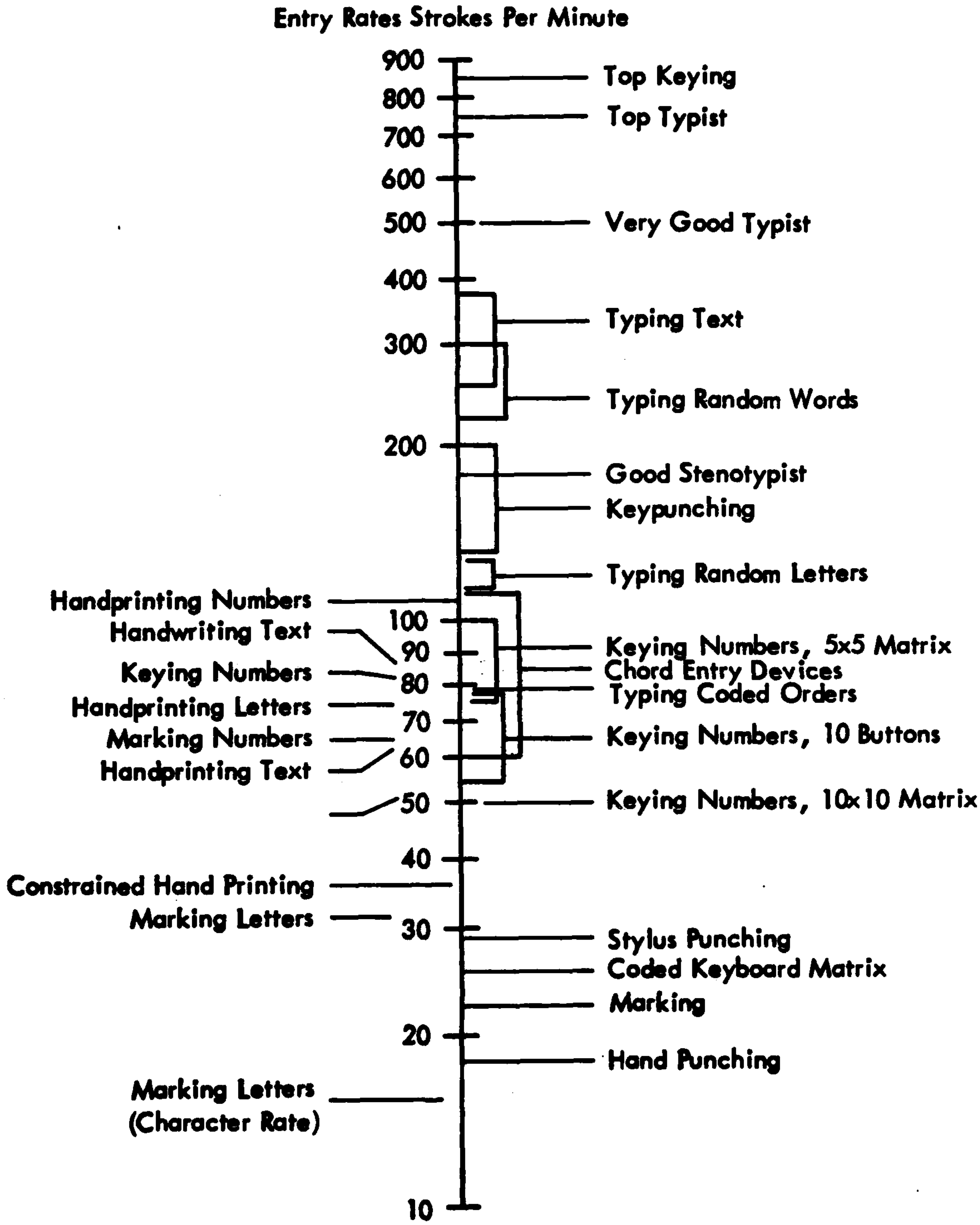


Figure 4.10 A Comparison of Entry Rates (from Devoe, [DEV067]).

Table 4.5
<u>Comparison of Text Entry Techniques</u>

	Ergonomic Measures								
Techniques	Cognitive Load	Perceptual Load	Motor Load	Visual Acquisition	Motor Acquisition	Ease of Learning	Fatigue	Error Proneness	Feedback Type
Alphanumeric keyboard.	H	H	M	M	M	M	M	M	D
Chord keyboard chord.	H	L	M	M	M	L	M	H	D
Stroked character recognition.	H	L	M	M	M	L	M	H	C
Voice recognition.	L	L	L	L	L	H	L	H	D
Direct pick from menu with light pen.	L	L	M	L	M	L	M	L	D
Direct pick from menu with locator device.	L	L	L	L	L	L	L	L	D
Indirect pick from menu with locator device.				[See Positioning]					

5. Controlled Techniques

Fundamentally, each of the techniques described in Chapter 4 represents a task of choosing. Selection chooses from among a set of entities, positioning chooses a place in space, orientation chooses an angle in space, and quantification chooses a number. Similarly, pathing chooses a sequence of places or angles in space, while text entry chooses a sequence of selections from among that special set of entities, the characters.

The set of controlled techniques is another set of fundamental tasks whose purpose is, instead, to form and transform visible objects, usually by a process of continuous modification. These tasks, and the techniques which carry them out, are tasks which are directed to an object which in some sense exists and is modified to satisfy a conception of what it ought to be.

In this chapter we provide descriptions of the techniques used to accomplish the controlled tasks. These techniques are grouped under the headings of stretching, sketching, manipulating, and shaping.

5.1. Stretching Techniques

A stretching technique involves taking a target object (a line, a triangle, a circle, a rectangle, or a prism) and distorting its shape by coercing one of its points to coincide with a specified position.

Because a positioning (of the movable point) is an intrinsic part of the task, all of the richness of technique inherent in the positioning task (see Figure 3.2) is inherent in the variety of stretching techniques. In particular, stretching techniques can be classified according to whether they are performed with continuous or discrete feedback, and whether they are direct or indirect. They can also be exercised in two or three dimensions. (See Section 4.2.)

In this section, we discuss the techniques for stretching independently of the choice of positioning technique used. In essence, stretching techniques differ from corresponding positioning techniques only in the choice of the form of the object being stretched and the manner of stretching. Generally, stretching techniques based on continuous feedback positioning techniques are far more useful than those based on discrete feedback.

5.1.1. Stretched Lines

The rubberband line is a stretching task which maintains a line extending from a reference point to a point specified by a positioning technique. As the latter point is moved, the line is modified to follow. The effect is like that of a rubber band stretched between a fixed point and a moving cursor.

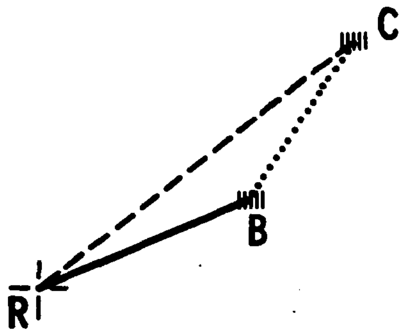


Figure 5.1.
A rubberband line.

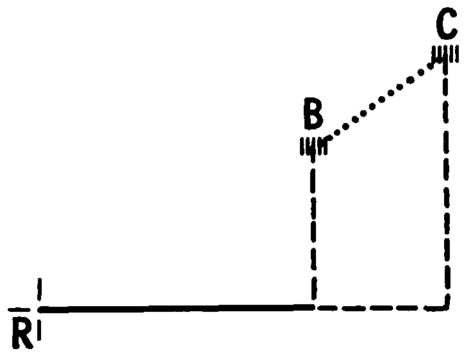


Figure 5.2.
A stretched horizontal line.

(a) Rubberband Lines

Summary: A line is stretched between the reference point and the point specified by a positioning technique.

Prerequisite Devices: As required for positioning.

Description: The rubberband technique, in its most basic form, makes use of an echo position (cursor) and a reference point. The object is to display a line from the reference point to another point on the screen. The user selects the reference point by pointing and then signalling acceptance of the cursor position (with positioning and selecting techniques, respectively). Further motion of the cursor from the reference point to the desired endpoint causes a line to be stretched (like a rubberband) from the reference point to the cursor (see Figure 5.1). Moving the cursor from B to C (along the dotted line) causes the displayed line to be displaced to the line from R to C.

The technique of rubberbanding is useful in building sketched forms, connecting lines in graphs, and in creating forms for further manipulation and analysis. Often, however, connecting lines are desired which are made up of only horizontal or vertical segments. A number of techniques and variations for doing this is listed below.

(b) Stretched Horizontal (Vertical) Lines

Summary: A line is stretched horizontally between a reference point and the x-coordinate of a point specified by a positioning technique and the y-coordinate of the reference point (Fig. 5.2). Vertical stretching is analogous.

Prerequisite Device: As required for positioning.

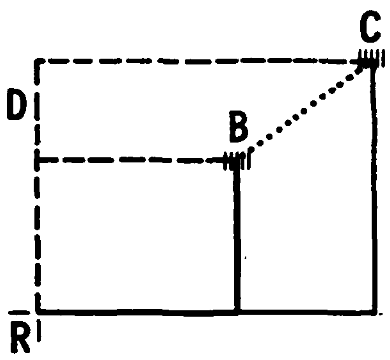


Figure 5.3.
Displaying x and y.

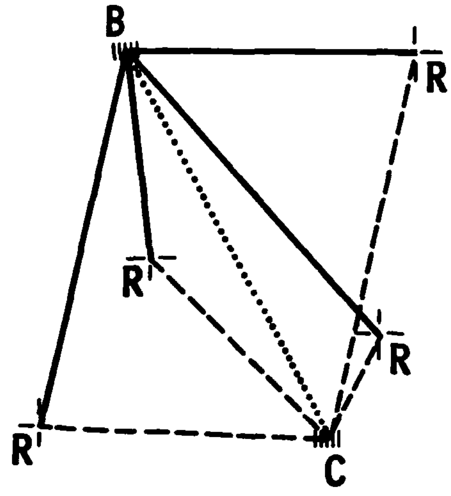


Figure 5.4.
A rubber vertex.

Variations on this technique include:

1. Combining constrained horizontal with constrained vertical may produce a system which acts like a constrained vertical if the angle between the vertical line through the reference point and the line through the reference point and the cursor is less than forty-five degrees, and

2. Displaying the x and y components of the line between the reference point and the cursor (Figure 5.3).

(c) Rubberband Vertex

Summary: A set of lines is drawn from a set of reference points (not necessarily coplanar) to a single point specified by a positoning technique. In other words a number of rubberband lines are drawn from the reference points to a common cursor (Figure 5.4).

Prerequisite Device: As required for positioning.

(d) A Zig-Zag

Summary: A zig-zag displays one of two possible paths: either horizontally leading or vertically leading form the reference point (Figure 5.5). Either or both of these two paths may be available depending on the system.

Prerequisite Devices: As required for positioning.

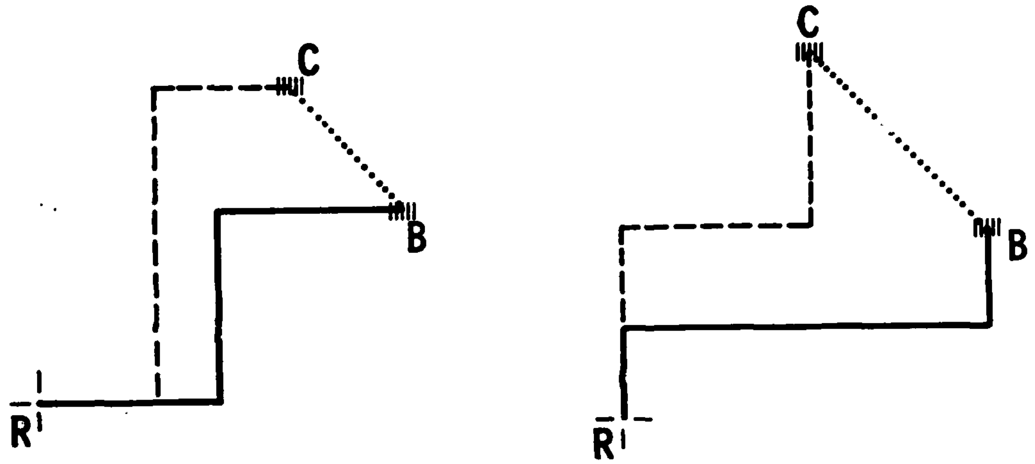


Figure 5.5. A zig-zag line (two alternatives).

5.1.2. Rubber Figures

Other figures can be stretched in a manner similar to the stretching of a line. A few are enumerated below, and are simply generalizations of the idea of rubberband lines and its variants.

(a) Rubber Rectangles

Summary: A rectangle is stretched so that one of its corners is at the reference point, and the diagonally opposite corner is at a point specified by a positioning technique (Figure 5.6).

Prerequisite Devices: As required for positioning.

(b) Rubber Circles

Summary: A circle is expanded with its center at the reference point, so that a point specified by a positioning technique is on its periphery (Figure 5.7).

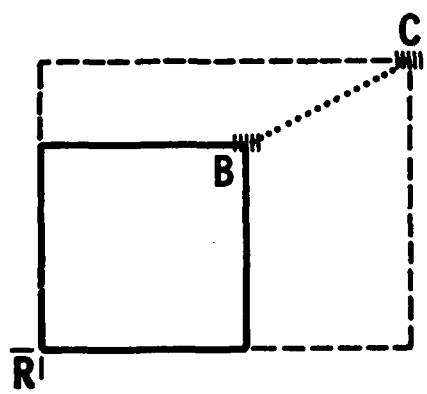


Figure 5.6.
A rubber rectangle.

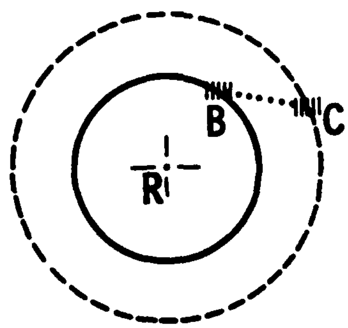


Figure 5.7.
A rubber circle.

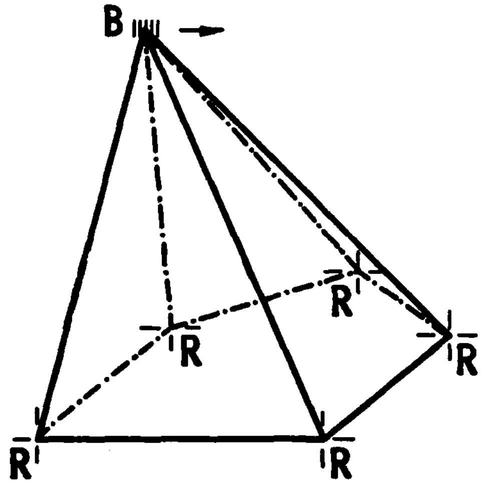


Figure 5.8. A rubber pyramid.

Prerequisite Devices: As required for positioning.

These two techniques may be generalized to regular figures with an arbitrary number of sides. They may also be generalized to three dimensions (rubber parallelopiped and rubber sphere).

(c) Rubber Pyramid

Summary: A three-dimensional rubber vertex is drawn, with reference points connected to form a closed base (Figure 5.8).

Prerequisite Devices: As required for positioning.

Note that this closed figure need not lie in one plane. Many other variations of these techniques are possible.

5.2. Sketching Techniques

The sketching task involves specification of a curved line, in two or three dimensions. The user specifies a starting position, a path, and its end. The requirements of this task, as determined by the application, are: dimensionality, resolution, sampling criterion, and smoothing method. Since the technique has a continuous-feedback positioning task embedded within it, all requirements associated with positioning are applicable, as in fact any positioning technique which satisfies the positioning requirements of the task can be used. Reference should be made to the positioning requirements and issues, as discussed in Section 4.2 of this report.

The sketching task is similar to the pathing task. It differs from the pathing task in that its whole purpose is to create a curve in space, whereas the pathing task is primariliy concerned with a temporal evolution of position or orientation. In sketching, the concern with time is primarily one of the skill of the user in creating his intended

effect with dexterity and dispatch. Nevertheless, the requirements and issues of pathing, as discussed in Section 4.4, are relevant. In particular, one has the issues of sampling criterion and smoothing method.

In sketching, the choice of whether to apply time sampling or space sampling is viewed as a requirement of the task, since the user will have in mind either the preservation of a shape with a desired granularity, or the preservation of features of the curve drawn with great care to be produced with the greatest faithfulness. In the former case, space sampling will be preferred; in the latter, time. It is also possible to combine the criteria, either in a weighted manner or according to a priority order (sampling first by the criterion which is met first).

The manner of approximation is also viewed here as a requirement of the task. Spline and piecewise polynomial approximations of degree greater than 1 will be preferred where general smoothness is desired, even at the expense of considerable heightening of the requirements for computation from the machine. The piecewise-linear line-segment approximation of the shape of the curve will be faceted at the approximation points, but is computationally simple and more readily implemented directly in hardware. Hence this approach is more likely to be acceptably responsive in a rapidly interactive application.

There are two fundamentally different approaches to sketching. Either a stylus or pen is used to trace the curve, or a crude curve is presented and then shaped by the user as desired. Only stylus sketching will be specified here. Shaping is described in greater detail in Section 5.4. Of course, 3D joysticks can be used instead of a stylus. We regard this as a variant of the stylus approach.

(a) Sketching Using Stylus or Pen

Summary: A freehand drawing is provided, continuously following the path of a pen or a stylus-cursor.

Prerequisite Devices: As required for continuous feedback positioning.

Description: The position is sampled at time intervals or distances as specified. A continuous curve is updated on the screen to include each sampled position, until a signal (button depression) is given to indicate termination of the curve. (The curve remains or disappears according to the purpose of the sketching.) The curve is usually made of line segments joining the sample locations.

Variations include a stair-step, where the system connects the appropriately spaced points by displaying the x and y components of the distance between the samples (Figure 5.9).

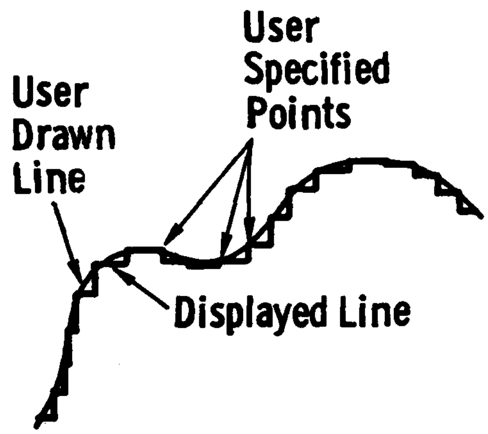


Figure 5.9. Sketching, with stair-step "smoothing."

5.3. Manipulating Techniques

"Manipulating" refers to operations performed on a displayed object where the form of the object remains unchanged, but position and orientation are changed. The requirements are generally the same as they are for positioning and orientation task, and the reader is referred to those sections (Sections 4.2 and 4.3).

5.3.1. Dragging

A drag occurs when the user picks or locates an object on the screen (e.g., a circle or a cube) and moves it to a new location on the screen. For instance, suppose a sphere is located on the left side of a CRT screen. The user drags the sphere to the right side of the screen by moving a locator (or pick) to the sphere, and then moving the locator (or pick) across the screen to the new location (Figure 5.10). The movement of the object is normally continuous during the dragging.

(a) Dragging Using Stylus or Pen

Summary: An object is moved so that a reference point on the object coincides with a point specified by a positioning technique.

Prerequisite Devices: As required for positioning.

Variations are derived from the use of other positioning techniques and devices.

5.3.2. Twisting

Twisting occurs when a displayed object is caused to rotate about an axis. This process is analogous to turning an object around in one's hand (Figure 5.11). The axis would have been chosen by picking a line or by a position and orientation. The degree of twist is specified by a quantifying technique. The movement is normally continuous.

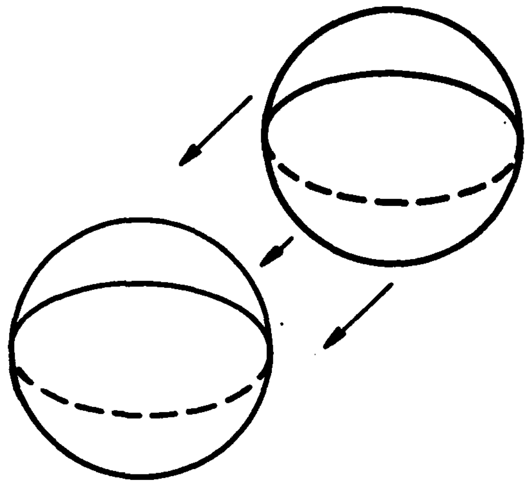


Figure 5.10. Dragging a sphere.

(a) Twisting Using Dial

Summary: An object is made to rotate about a specified axis.

Prerequisite Devices: As required for quantifying.

5.3.3. Scaling

Scale refers to how large the displayed object appears on the screen. By manipulating the scale, one may cause the object to appear larger or smaller on the display (independently of other displayed objects). The scale is specified by a quantifying technique.

(a) Scaling Using a Dial

Summary: An object is adjusted in size.

Prerequisite Devices: As required for quantifying.

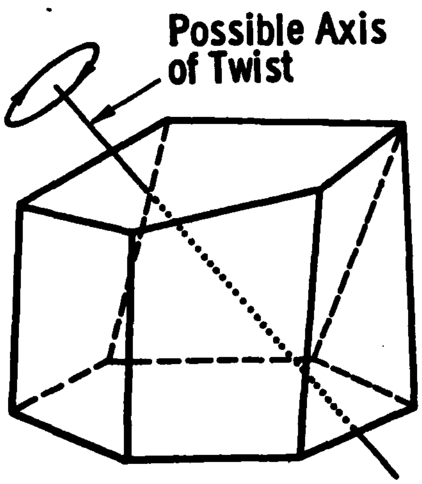


Figure 5.11. Twisting an object (hidden lines shown dotted).

5.4. Shaping Techniques

Shaping refers to molding a curve or surface until it reaches some desired shape. In interactive graphics systems, shaping is highly dependent on how lines and surfaces are represented inside the system. Shapes may be represented by control points. These control points exert an influence on different parts or the whole shape. In other words, given the control points, one may specify a particular shape. Two common shape representations using control points are the Bezier method and the spline method. In the Bezier method, the control points exert influence on a particular blending function. This blending function, coupled with the control points, defines the shape. (The control points may not lie on the shape.)

5.4.1. Adjustable Curves

Complex curved lines in two or three dimensions can be represented and displayed using any of a number of representation techniques. Usually, a curve is desired which lacks corners or cusps. Therefore splines and Bezier functions are usually used.

In splines, the curve is represented by control points which lie on the curve, and the curve is constructed using piecewise polynomial representations (usually cubic which maintain continuous first derivatives between the pieces). With Bezier representations the control points are generally external to the curve, but nevertheless control the shape.

The most common technique for shaping a curve is by allowing the user to drag the control points, using the stylus or pen (see Section 5.4.1). For a discussion of approximation (smoothing) methods, see [FOLE81,NEWM79].

(a) Flexing Using Stylus or Pen

Summary: A curved line is reshaped by moving control points.

Prerequisite Devices: As required for selection and positioning.

Description: Displayed control points are selected and dragged to a new position, causing the displayed curve to change shape.

5.4.2. Adjustable Surfaces

The shaping of surfaces, as with curved lines, is highly dependent on the way surfaces are represented in the system. Basically, the two methods described in the previous section may be extended to be applicable to surfaces by taking the cartesian product of two curves representing the cross sections of the surface. The surface itself is drawn by keeping the parameterizing variable in one cross section equation constant and varying the parameterizing variable in the other cross

section equation. The process is then repeated keeping the parametrizing variable of the second equation constant. Using the Bezier method, continuity is maintained at boundaries of Bezier surfaces by insuring that the common control points and the adjacent control points are all colinear across cross sections, and that the ratio of the distances of the common control points to the adjacent control points is constant across cross sections. B-spline surfaces are also formed by taking the cartesian product of two B-spline curves [FOLE81,NEWM79].

(a) Forming Using Locators

Summary: A curved surface is reshaped by moving control points.

Prerequisite Devices: As required for selection and positioning.

Description: Displayed control points are selected and dragged to a new position, causing the surface representation to change in shape.

6. Conclusions

In this final section we first review what we have done, and then suggest directions for future work.

6.1. Summary

In this research work we have proposed an organization of interaction techniques based on the user task which the technique performs. We suggest that task requirements serve to limit the set of techniques which can be considered for a particular application. We have enumerated the characteristics for a variety of techniques, and discussed many of the considerations important to their effectiveness. Relevant experimental and experiential comparisons are tabulated.

How does one select from the set of feasible techniques? In some cases experiments or experience can aid. In general, the perceptual, cognitive, and motor loads of each technique can be considered. However, we do not quantify these loads. We do suggest a diagramming method (Appendix A) which may assist in such quantification.

Interaction techniques cannot be selected in a vacuum. The context in which they are used, as discussed in Chapter 2, is crucial and is not accounted for by experiments. Experience, however, shows the importance of perceptual, cognitive, and motor continuity from one interaction task to the next, particularly (but not exclusively) within a single sentence [FOLE74].

6.2. Research

Research directions are best set in the context of a long-range goal. Our goal is a model of user-computer interactions which can predict the performance of both new and skilled users of various interaction techniques. While this goal may never be completely achievable in practice, it can act as the motivator for research.

The first step in developing such a model is the identification of basic interaction tasks. We have suggested one such set, but there may be others. Our tasks do not account very well for the substantial differences between positioning by coordinate pair type-in and by explicit pointing at a location on the display surface, nor between operand name type-in and explicit pointing at the displayed operand. In both cases, use of the wrong type of technique forces the user into a cognitive process, converting from one representation to another. Perhaps this is just another example of the cognitive analog to motor and perceptual continuity from one step in the user-computer dialogue to the next. Whatever the case, more work is needed in this area with respect to interaction tasks.

Given tasks, the next need is a way to characterize interaction techniques in such a way that their perceptual, cognitive, and motor components are identified. The interaction technique diagrams discussed in Appendix A are our starting attempts in this direction. We found them to be essential in precisely defining the various experiments. Some formalism such as these charts can be crucial.

The next step is to continue where the diagrams leave off, tying together a series of interaction tasks as would be done in a real user-computer dialogue, representing the various types of discontinuities we have discussed, and also representing the characteristics of sentences in the interaction language.

A most difficult step is to quantify the perceptual, cognitive, and motor processes, in terms of the time they take. This is difficult because many factors must be considered -- in menu selection, for example, we must account for the size of the menu, where it is positioned, and the symbolic representation used (i.e., text vs. iconic). Our starting model here would be the work reported in [CARD80], in which the motor and cognitive components of a few selection, positioning, and text entry techniques have been successfully quantified for skilled, well-trained users performing routine tasks with keyboard and mouse (a locator). A first step would be to extend their "keystroke-level model of user interaction" to include additional techniques/devices, and to also account for the perceptual steps of visually acquiring a menu or cursor.

A final step, perhaps concurrently achieved, is to quantify the other criteria for interactive performance (learning time, recall time, memory load, error susceptibility, and naturalness), and to relate them to the work factors (perceptual, cognitive, and motor).

Perhaps, also, this catalog of techniques should be augmented to include all known useful techniques.

What is the role of experiments in all this? The types of experiments we have described, while useful, provide very limited and specialized knowledge which is hard to generalize for use in new situations. The proper role of experiments should be to:

1. Obtain basic performance data to be used in overall model(s) of user-computer dialogues.

2. Verify the dialogue model(s).

Given verified models and the basic data they require, the models would be used to quantitatively evaluate individual interaction techniques and sequences of interaction techniques.

APPENDICES

A. Interaction Technique Diagrams

The interaction techniques, while they represent elementary tasks at the lexical level of communication, can nevertheless be subdivided into a number of separate steps. These steps are generally combined unconsciously by the user to achieve a task. In the positioning task, for example, the user ordinarily must first grasp a device and move his eye to a cursor position on the screen. He then operates the device by feedback-closure with a desired position until the target and cursor are coincident. Then there may be a separate act to indicate satisfaction.

The study of the effectiveness of techniques, and their comparison according to various measures can be assisted by abstract models of such activity. By attempting to create and evaluate such models, the process of comparison can be become qualitatively less empirical and more systematic.

To this end, we have explored a diagramming technique which exhibits the steps within a task and assigns simple measures of effort to each. This technique has been employed in evaluating various measures of cognitive, perceptual and motor load (Chapter 4), as well as in describing the objective of experiments (Appendix B). We have called this representation an interaction technique diagram.

Our diagrams are not as detailed as the Labanotation [HUTC70], but unlike that notation they represent more than the motor activity. The level of detail, however, appears to be more consistent with our present level of quantitative knowledge of work.

Like a flow chart, an interaction technique diagram depicts the basic functionalsteps, their flow-dependencies, or the sequence or order in which steps are to be completed before other steps can be started. Unlike flow charts, the dependencies are not strictly sequential, since the steps involved in interactive graphic input are not sequential. For example, the user of a positioning technique must perceive the locator device and the prompting cursor before he can move the device productively. Yet the order in which he does these perceptual steps is immaterial. In fact an experienced user may do both steps simultaneously, reaching for the device while moving his eye to the screen.

Our diagrams are consequently based on a common model for concurrency, the Petri net [PETE77], freely adapted to our purpose.

A.1. Basic Elements and Symbology

There are five basic components to an interaction technique diagram: the task steps or activity to be performed by the user, an operational step performed by the machine, a synchronizing condition, a decision taken by the user, and a decision taken by the machine. The symbols used in the diagram for these components are illustrated in

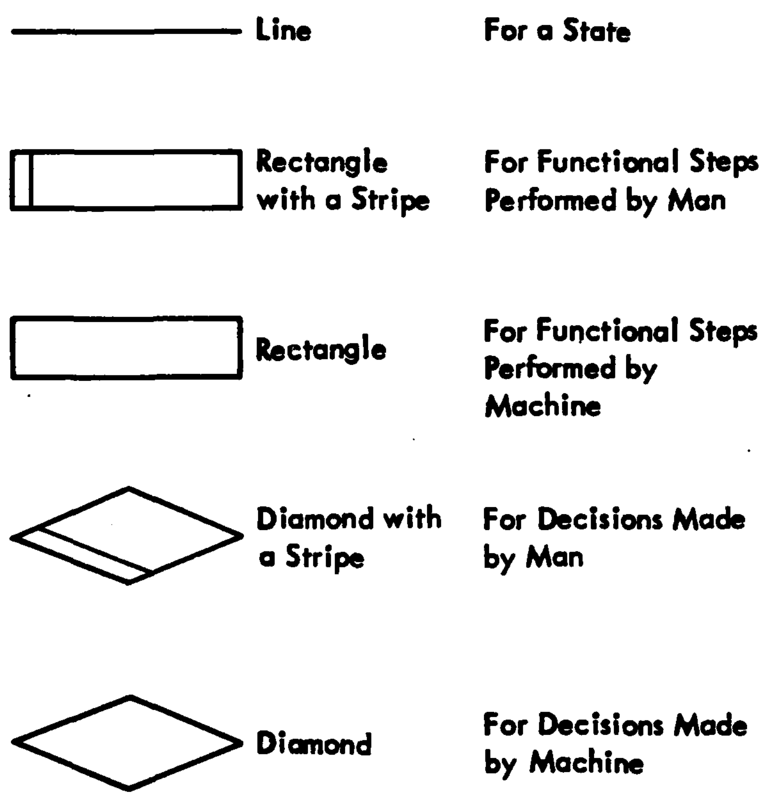


__Figure A.1.__ Symbolic elements for technique diagrams.

Figure A.1. The rectangular blocks represent a functional step. The right (larger) sector of the rectangle describes the activity. Upon completion of the activity, one activity, or more than one simultaneous activity, may ensue.

The synchronizing symbol, a "bar" across paths, indicates that all steps leading to the bar must complete before the steps following the bar are (simultaneously) begun. Thus, the synchronizing symbol represents a "state" in which a thread of activity may wait because another activity is not yet complete.

The decision symbol indicates which step is to follow the step leading to it, on the basis of the action.

A.2. Functional Steps and Control Flows

There are three control flows in an interaction technique: sequential, concurrent, and conditional. In any control, there are functional steps performed by the user and system steps performed by the computer. In the pen tracking technique, the act of acquiring the lightpen and the tracking cross are functional steps to be performed by the user. These

user-performed functional steps are represented by rectangles with a stripe. The brief description of the respective steps appears in the main area of the rectangle. Each of these functional steps is categorized as cognitive, perceptual, and/or motor. The categorization is dependent upon whether cognitive, perceptual, and/or motor activities dominate the step. The categorization of the nature of the steps appears in the smaller area of the rectangles, with C, P, and M representing cognitive, perceptual, and motor, respectively. The cognitive and perceptual steps are unrealized to the computer; only a portion of the motor steps will be known to the computer. The activation of a switch on the lightpen is one such step.

Just as there are user-performed steps, there are computer-performed steps. Where a tracking cross is lost during pentracking, in certain systems, the machine will do a raster scan of the screen to relocate the position of the pen. This is a machine-performed system step, represented in the technique diagram as a rectangle.

In sequential control flow, there is a temporal relationship between steps. A step, say step A, has to be performed before another step, say step B, begins. In other words, upon completion of step A, the interaction technique is said to enter a new state. An interaction technique is in a new state when one or more flow steps can be performed after receiving the necessary information or consequence of operation from the former step(s). Using the pentracking technique example, the interaction technique is ready to enter a new state in which the user can now point at the tracking cross with his lightpen only after he has acquired the lightpen and the tracking cross on the screen. Each state is depicted by a horizontal line. The numeral which appears in the circle represents the state which the technique is in. The initial state is numbered 1 and the numeral increases by 1 each time the interaction technique enters a new state.

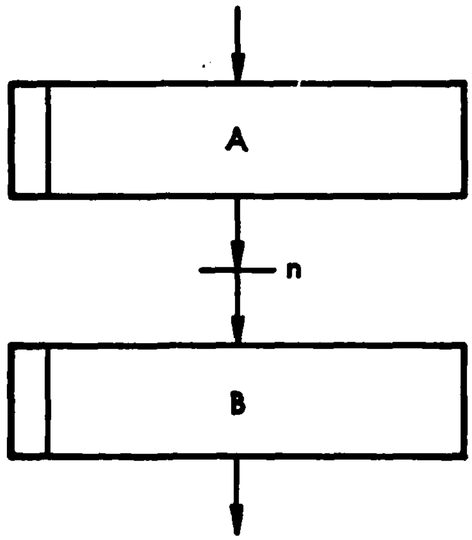


Figure A.2. Sequential flow of control.

In its diagrammatic form, the sequential flow control of the technique will look like Figure A.2. To enter state n, step A has to be performed. It is only upon the completion of step A that state n will be reached and step B can be started.

In concurrent control flow, the sequencing of steps is not important. To enter a new state, two or more steps have to be completed. The activities involved in each step can occur simultaneously, or in any order. Figure A.3 illustrates a particular instance of such a flow control mode.

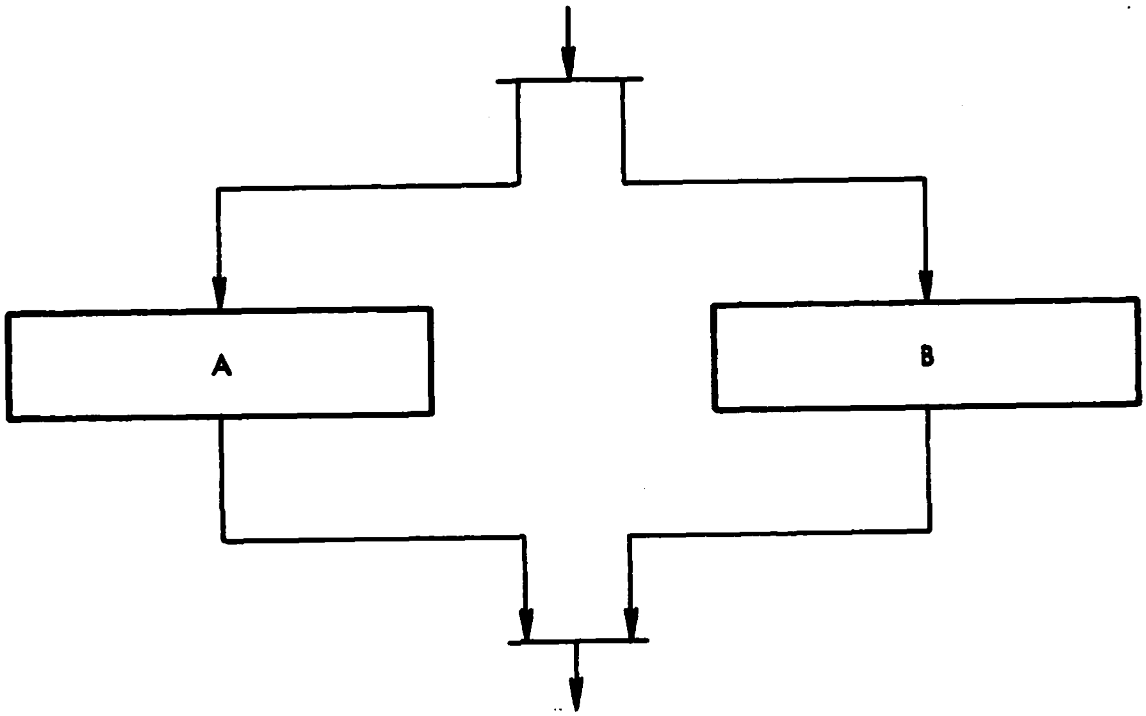


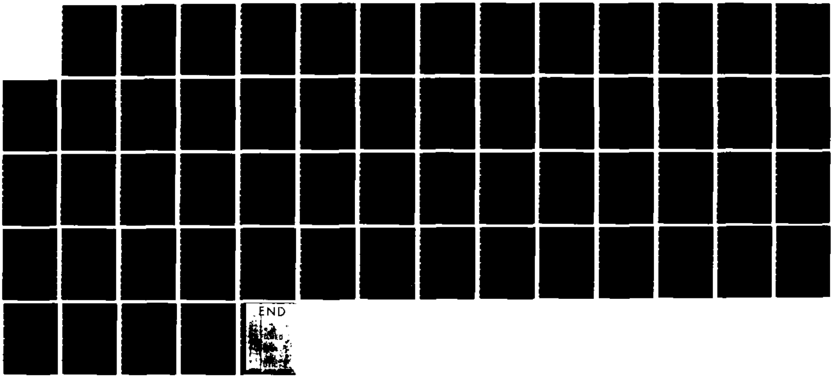
Figure A.3. Concurrent flow of control.

Figure A.3, in which steps A and B must be completed before state 2 is entered, illustrates this concurrency between steps.

Then there is the third kind of control flow--the conditional control flow. This control flow involves a decision making process depicted by the diamond-shaped symbol with or without a stripe and a brief description of the decision involved in the process. Some of the decisions are user-initiated decisions and others are system-initiated decisions. In either case, there will be two out-directed lines leaving this diamond-shaped symbol, as in an IF-THEN-ELSE programming situation. The lines are labelled with the decision results, such as "yes" and "no," "true" and "false." User decisions are, of course, cognitive steps. They are represented as diamond symbols with a stripe with the letter C in the smaller area of the diamond.

AD-A136 605 THE HUMAN FACTORS OF GRAPHIC INTERACTION: TASKS AND TECHNIQUES(U) GEORGE WASHINGTON UNIV WASHINGTON DC DEPT OF ELECTRICAL ENGIN.. J D FOLEY ET AL. DEC 80 2/2

UNCLASSIFIED ARI-TR-508 MDA903-79-G-01 F/G 9/2 NL



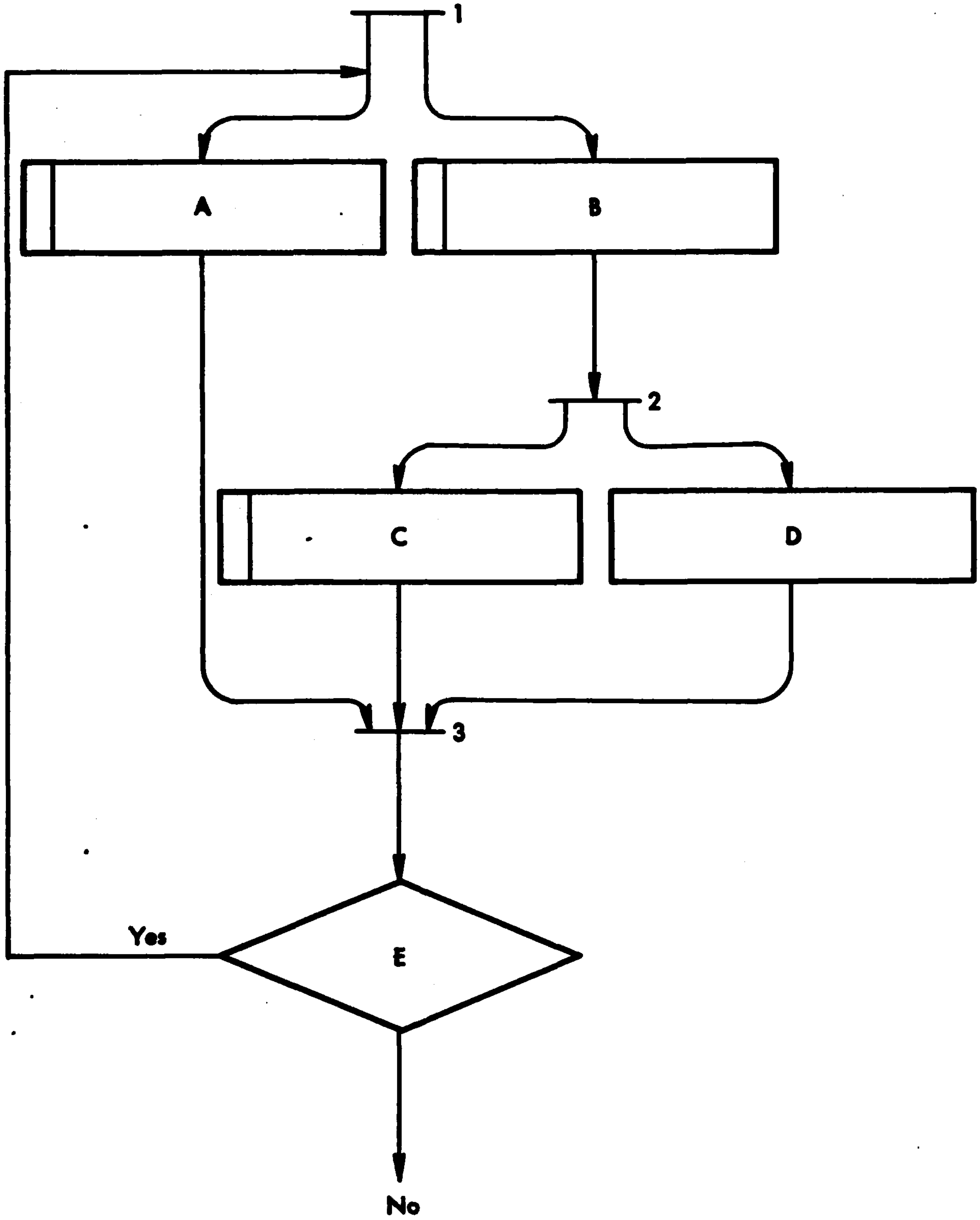


Figure A.4. An interaction technique diagram.

It is in the conditional control flow that looping and interaction can occur. Figure A.4 illustrates this flow.

After state 3 is reached, the system makes a conditional decision. The result of the decision determines the flow of control of the techniques. In this case, the "yes" outcome causes an interaction to repeat step A, while the "no" outcome transfers control.

A.3. The Making of Interaction Techniques Diagrams

When making Interaction Techniques Diagrams, two basic notions are necessary:

1. Break down the technique into steps. Determine whether these steps are system-performed steps or user-functional steps and the algorithm flow involved. Just as with programming design, the decision of how far to decompose the techniques depends on the usefulness of doing so. Here the level of detail is a pragmatic decision of the designer!

2. Capture the steps in their symbolic form. While doing so, the designer will also have to determine the main element of activities involved. In other words, he will have to determine whether the step is essentially cognitive, perceptual, or motor. No step is purely cognitive, perceptual, or motor. The amount of the load imposed by the step on the cognitive, perceptual, or motor skill of the operator will determine the nature of the task. Taking the step of acquiring the lightpen, the cognitive work to make the decision to acquire and the perceptual work to locate the lightpen are minimal compared to the act of moving the hand to grasp the pen, making the acquiring of the lightpen essentially a motor step.

When effectively accomplished, the making of interaction technique diagrams can:

1. Provide an overall graphical representation of the technique examined, hence reducing the volume of written descriptive material, and at the same time aiding the discussion, comparison, evaluation, and understanding of it.

2. Assist the designer of interaction technique in effectively seeing the essential steps in the technique.

3. Assist the designers of human factors experiments in seeing if there are unnecessary or biased operations in the experimental procedures.

4. Facilitate the spotting of potential bottlenecks which can lead to the easing of the flow of work load in these step phases.

5. Make evident the differences between the interaction technique and its variation.

6. Be able to relate each step to operator characteristic.

7. Determine the amount of cognitive, perceptual and motor work load involved in different techniques to enable subjective evaluation.

This list is by no means all-inclusive. The designers will certainly find the methodology useful in other ways after it is actively employed.

B. Experiment Summaries and Reviews

In this appendix we summarize and critique the experiments known to us which deal with interaction techniques. The basic results of the experiments are integrated into the discussions and recommendations of Chapter 4, Interaction Techniques.

There are two key questions which must be asked of each experiment:

1) How strong are the results, and

2) Can the results be generalized beyond the specific experimental setting?

The purpose of these summaries is to help answer these questions. Thus we describe the experimental methodology, the types of tasks involved, and the characteristics and number of subjects involved. Included with these summaries are the technique diagrams modified to depict the various tasks involved in the interaction techniques evaluated in the experiments. Some of these tasks are not required in the original techniques but are placed there to make monitoring of the experiment possible. These diagrams are included to help describe the experimental procedures and identify possible flaws. Perceived flaws which tend to limit the strength or generality of the conclusions are discussed.

The experiments are organized according to the interaction task to which they most closely correspond. We call particular attention to the selection experiments, most of which involve moving a cursor to the target to be selected. We believe the major findings of these experiments hold for the 2D positioning task; the difference is that there are no displayed targets in the positioning case. Rather, the user has in "the mind's eye" a desired position which corresponds to the target in the selected task.

B.1. An Evaluation of Devices for Text Selection (Card, et.al.)

CARD78 Card, S.K., English, W.K., & Burr, B.J., "Evaluation of Mouse, Rate-Controlled Isometric Joystick, Step Keys, and Text keys for Text Selection on a CRT," Ergonomics 21, 8 (August 1978), 601-613.

The experiment evaluates different devices for selection in a text-editing environment. The devices compared are: a mouse, a velocity-controlled isometric joystick, a group of step keys, and a group of text keys. Both the step keys and the text keys are cursor control keys. The step keys move the cursor up, down, left, right, or to "home" at the upper left corner of the display, while the text keys move the cursor forward and backward through the text in units of paragraph, line, word,

and character. Results from the study show the mouse to be the fastest and the most accurate device, followed by the joystick, the text keys, and the step keys. On the whole, the closed-loop feedback devices (the mouse and the joystick) are found to be superior in both speed and accuracy to the open-loop feedback devices (the step keys and the text keys) for selection. The experiment was extremely well conducted and the tasks the subjects performed were well monitored and described. We believe the results for the mouse, joystick, and step keys can be generalized beyond text editing applications. The use of text keys assumes a certain structure for the displayed information (paragraphs, lines, etc.), and hence do not generalize as well.

Four subjects, all inexperienced with the devices, were used. Subjects were asked to move the cursor from random initial positions to a word or a phrase highlighted by reversing the intensity of the target and its surrounding background. Each subject used each device, in a randomized order. There is no discussion of transfer effects, but one suspects they would be relatively minimal in any case.

The experiment starts with a display of alphanumeric text, within which the target is embedded. While not explicitly stated in the paper, the cursor is presummed also to be visible on the display.

As indicated in the various technique diagrams (Figures B.1 to B.4), the subject first visually acquires the target and the cursor, then strikes the space bar with his right hand to start a trial. With the same hand, he then reaches for the device and directs the cursor to the target. When the cursor is on the target, the subject acquires and presses a button to indicate "done." For the mouse, the button is on the device itself. The C/D ratio for the mouse was 1:2.

The experiment was repeated with different target sizes and locations to generate 2,000 different trials. Subjects performed about 600 trials a day over a 2 to 3 hour period until they reached the point that positioning time no longer decreased signficantly with practice. The average learning phase was from 1,200 to 1,800 trials.

The learning curves for the subjects' use of the four devices are quite revealing. When the subjects were novices, their positioning times for the mouse and joystick were essentially the same, at 2.2 secs. The time with the step keys was 3.0 secs.; for the text keys, 3.9 secs. After the learning phase ended, positioning time with the mouse dropped to 1.3 secs.; with the joystick, 1.6 secs.; step keys, 2.3 secs.; text keys, 2.0 secs. Thus the mouse emerged as the fastest of the four devices for positioning. The text keys, despite their fourth place position for novices, proved faster than the step keys for skilled users. This is presumably because the text keys are more powerful, but are just harder for a novice to use.

To compare the devices after learning was achieved, data on the last 400 trials were examined. Several measurements were taken: homing time, positioning time, total time, and error rates. Homing time, the time taken to acquire a device, is the time interval from when the subject strikes the space bar until the displayed cursor begins to move.

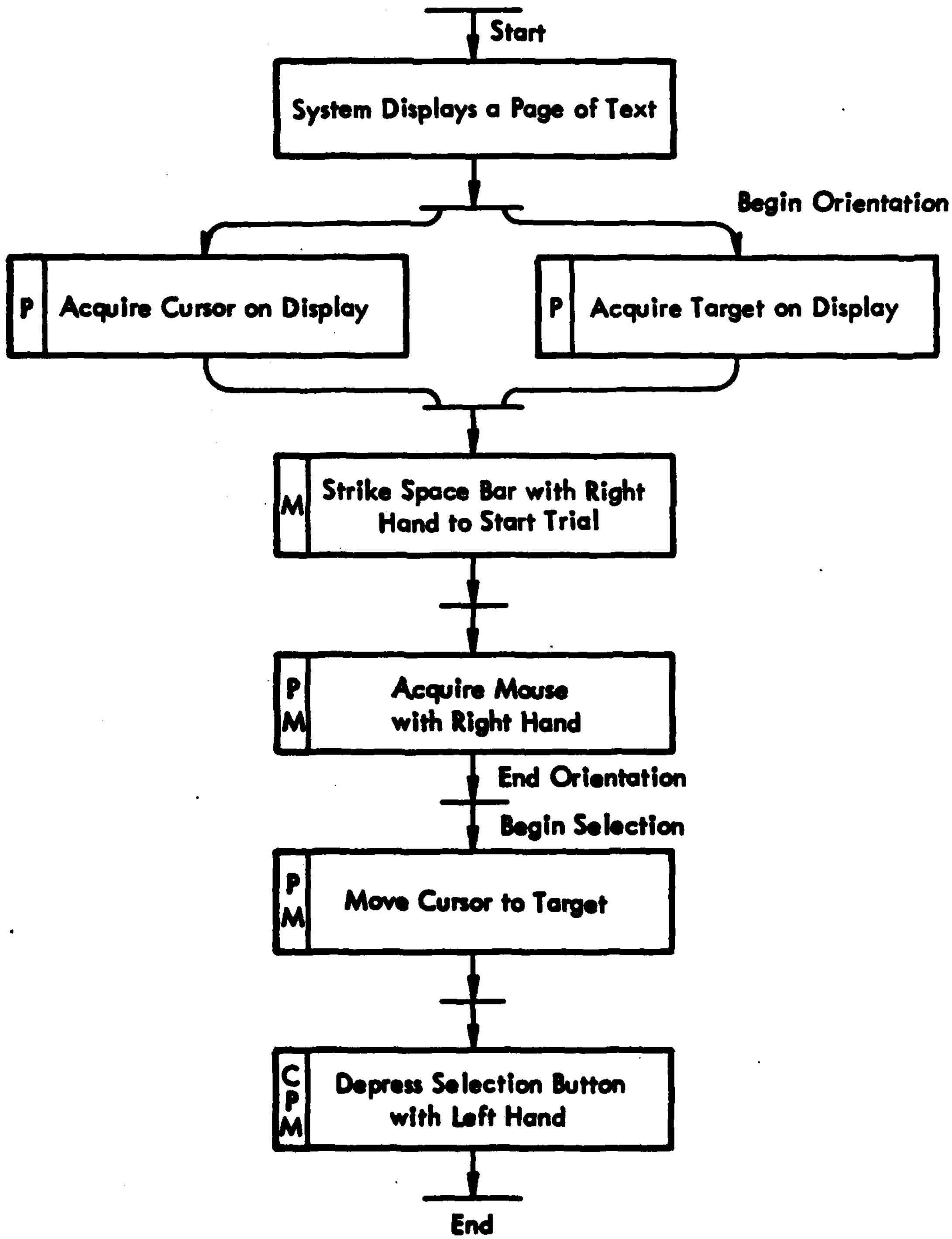


Figure B.1 Text selection using a mouse.

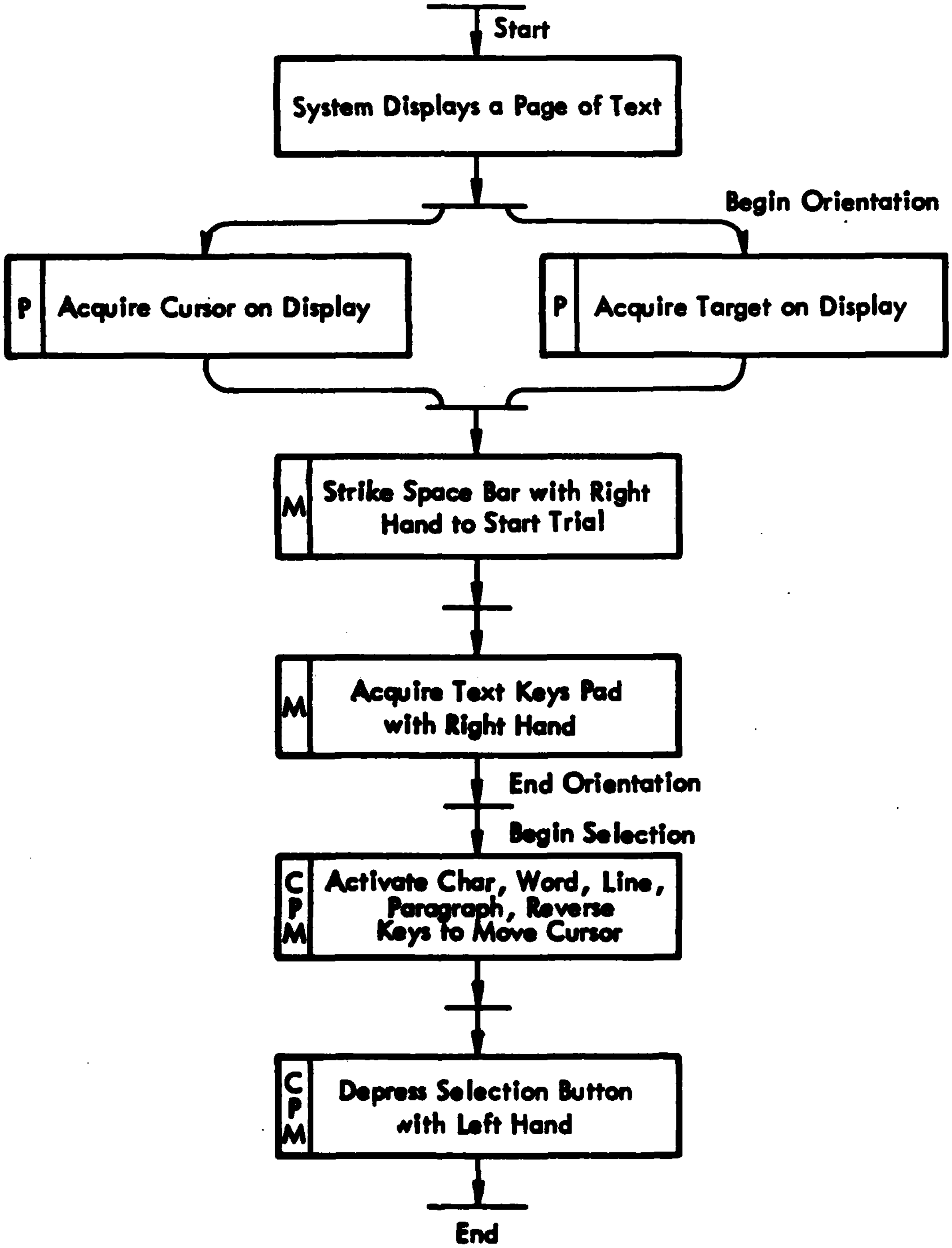


Figure B.2 Text selection using text keys.

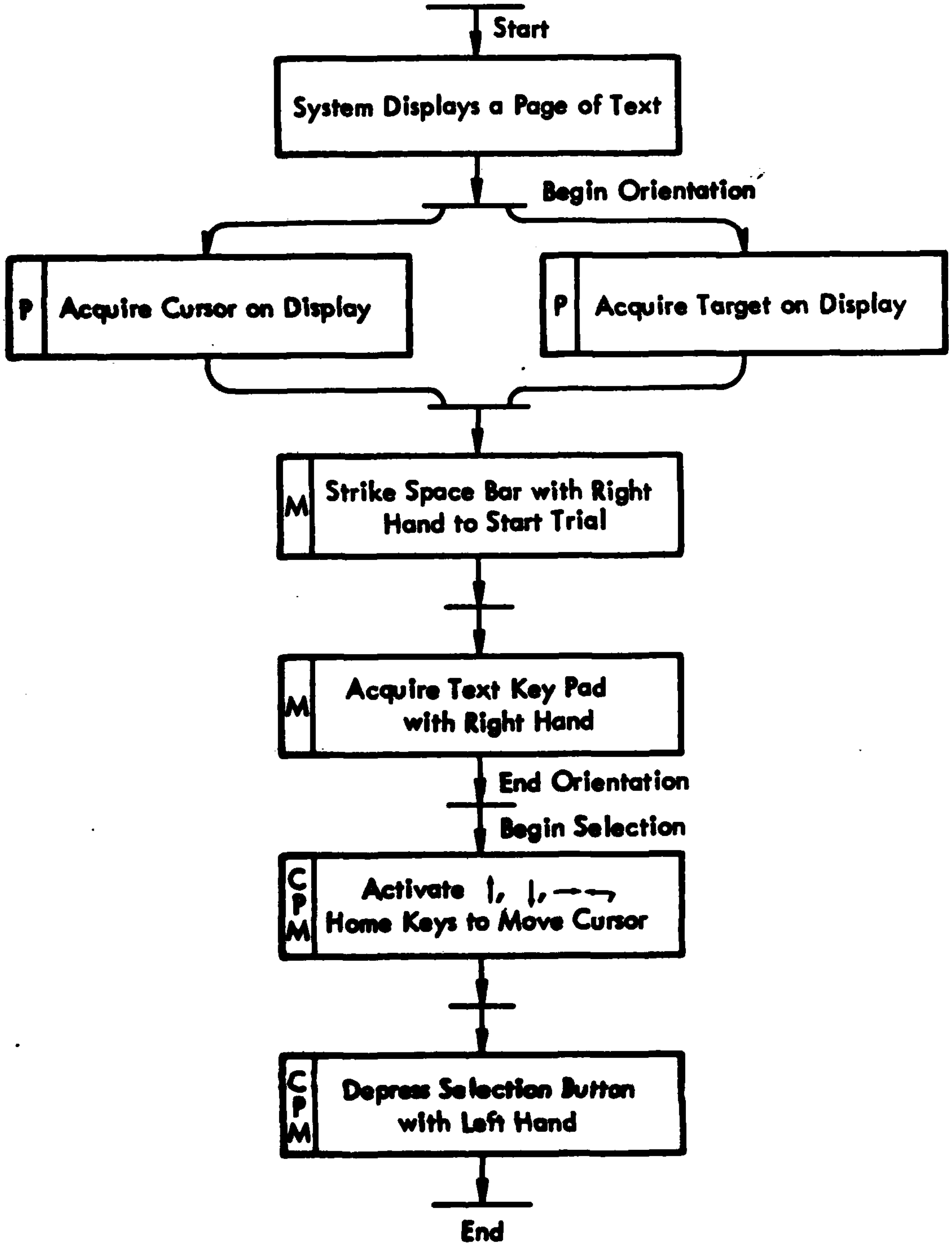


Figure B.3 Text selection using step keys.

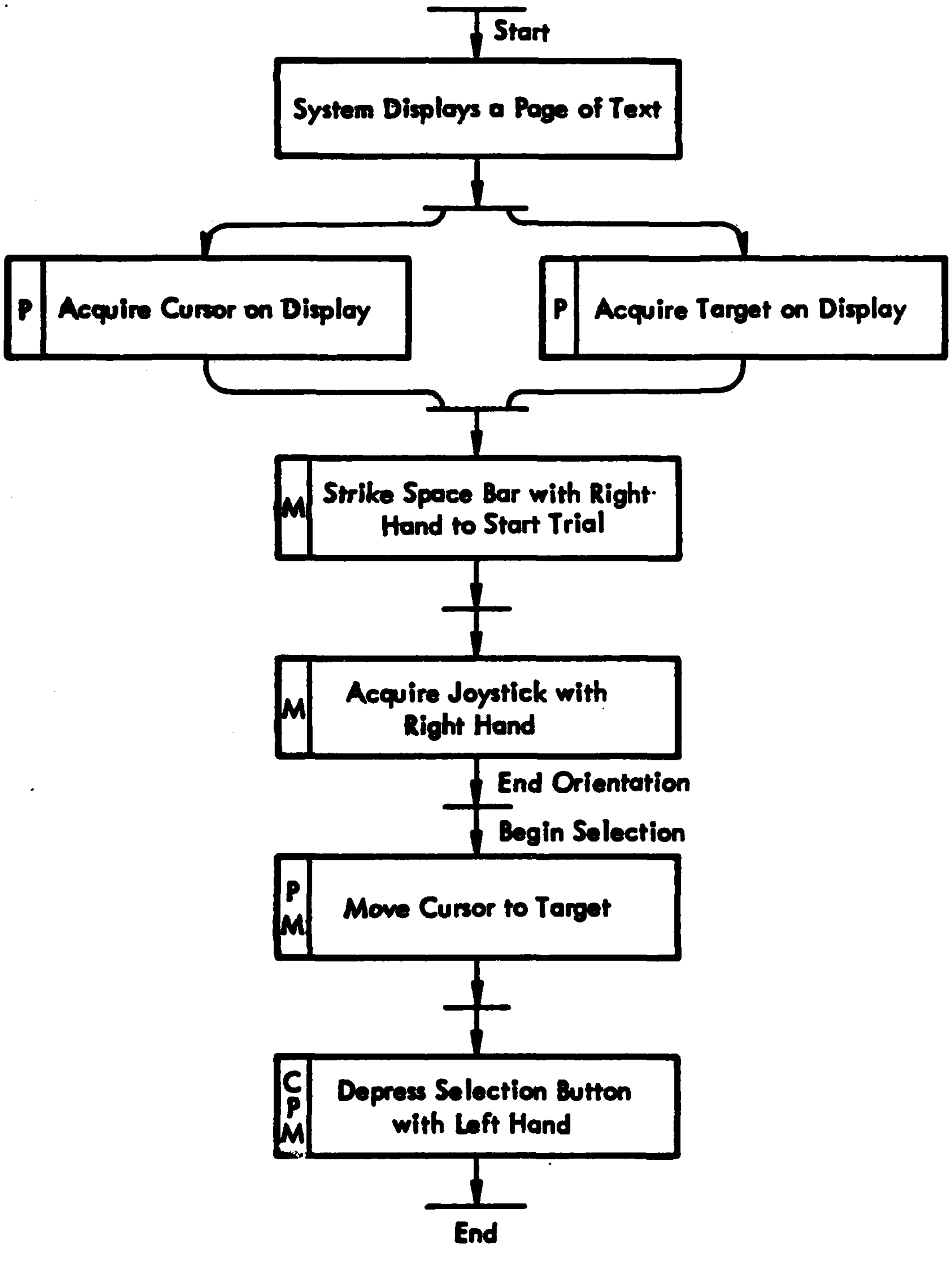


Figure B.4 Text selection using joystick.

Positioning time starts when the cursor begins to move and ends when the subject depresses the "selection" button. Total time is the sum of homing time and positioning time.

Homing time is longest for the mouse (0.36 secs. average) and shortest for the step keys (0.21 secs.). It is 0.32 secs. for the text keys, and 0.26 secs. for the joystick (which was mounted at the upper-right corner of the keyboard housing). The text keys, though closer to the keyboard than the mouse, have almost the same homing time as the mouse. The experimenters contend that the subjects tended to plan strategy for moving between hitting the space bar and actually activating the various text keys to move the cursor. This contention is supported by the relatively high standard deviation in the homing time observed for the text keys. The observation suggests that heavy cognitive activities were involved in using text keys for selection. In any case, homing time is relatively insignficant compared to positioning time. In terms of positioning time, the mouse fared the best, the joystick next best, then the text keys and the step keys, as described in the discussion of learning. The positioning time measurements verified Fitts' Law, which asserts that the positioning time is proportional to the log of distance to target divided by target size. In terms of error rate, again the mouse is the lowest (5%), and the step keys the highest (13%), with the joystick at 11% and text keys at 9%.

One can conclude from this experiment that among all devices tested, the mouse is easily the best. Because of the reliability of the results and the number of conditions examined, one can generalize the rankings of the devices (except for the text keys) to selection and positioning tasks in other graphics applications. The results are equally valid for new, inexperienced users and for skilled users that this is because the results are determined by physiological limits, which are largely insensitive to training. Card also is careful to point out that he has not proven the mouse to be the "best" device, as everyone seems to want to believe, only that it can't be improved upon in terms of speed, precisely because it is limited by human physiological capacities, not device capacities. For total ergonomic reasons other devices could prove preferable, but they could never be faster. It is probably possible to design a joystick, say, that is as fast as a mouse but not faster.

B.2. A Comparison of Selection Techniques (Earl and Goff)

EARL65 Earl, W.K. and J.D. Goff, "Comparison of Two Data Entry Methods," Perceptual and Motor Skills 20 (1965), 369-384.

This experiment compares the efficiency and accuracy of several selection techniques. In each case, three common words are shown to the subjects, who enter the words in one of three ways:

1) Picking with a light pen from a menu. The desired words are guaranteed to be on the menu.

2) Picking from the menu, but with no guarantee that the words are on the menu. The subject types any words not found on the menu. In cases 1 and 2, the menu size varied from 6 to 18 entries.

3) Typing in all three words.

The results showed 6.6 secs. for case 1, 7.5 secs. for case 3, and 7.1, 10.3, 12.3, and 12.6 secs. for case 2, when either 0, 1, 2, or 3 entries were not on the menu and were typed. For 18-entry menus, however, case 1 (selection) was slower than typing (7.9 versus 7.5 seconds). As the menu becomes larger, the typing time will remain fixed while the selection time will increase in proportion to the visual search time over the menu, at least for inexperienced users such as the subjects in this experiment. Experienced users, repeatedly selecting from a menu, will get to know where each entry is.

Error rates were substantially lower for menu selection (.5%) than for type-in (4.0%). Menu selection of course precludes the chance of typing error.

Twenty-four subjects, all inexperienced, were used. Each subject was asked to input three short and common words (ranging from 3 to 7 letters per word, with the majority of the words consisting of 4 to 5 letters). The experiment starts with the subject obtaining on the display console the three words to be input (by turning the exposed console display sheet up and letting it fall on the top of the console). Simultaneously, the subject can acquire the input device (the light pen for the first two techniques and the keyboard for the third technique). For the techniques which require picking from a menu, the subject has to scan the "menu," simulated by typewritten pages in formats of different sizes and arrangement of words, t acquire te words t be input (Figures B.5 to B.7). The light pen technique was simulated by marking across the word to be selected using a black grease pencil. The type-in technique was done by typing the target words onto a numbered sheet using a typewriter. The results show that the tasks which use only the light pen or the keyboard are significantly faster than the tasks that might involve using both devices, by a ratio of 1:2. Also, the two single-device tasks generally have fewer errors than the task that requires the use of both devices.

The finding is reasonable. A mixed-device selection technique with choices not guaranteed to be on the menu requires the user to carefully scan through the menu to find the entries. If found, the selection is made with the light pen. If not, the suject switches to the keyboard to type the entry. The user must remember which of the entries were not found and type them in. Furthermore, the input task time is really the sum of the visual search time for the target on the display screen, the pick time if the light pen was used, the text input if the keyboard was used, and the time to switch from one input device to the other if necessary. Therefore, the tasks which required using both the light pen and the keyboard would be slower.

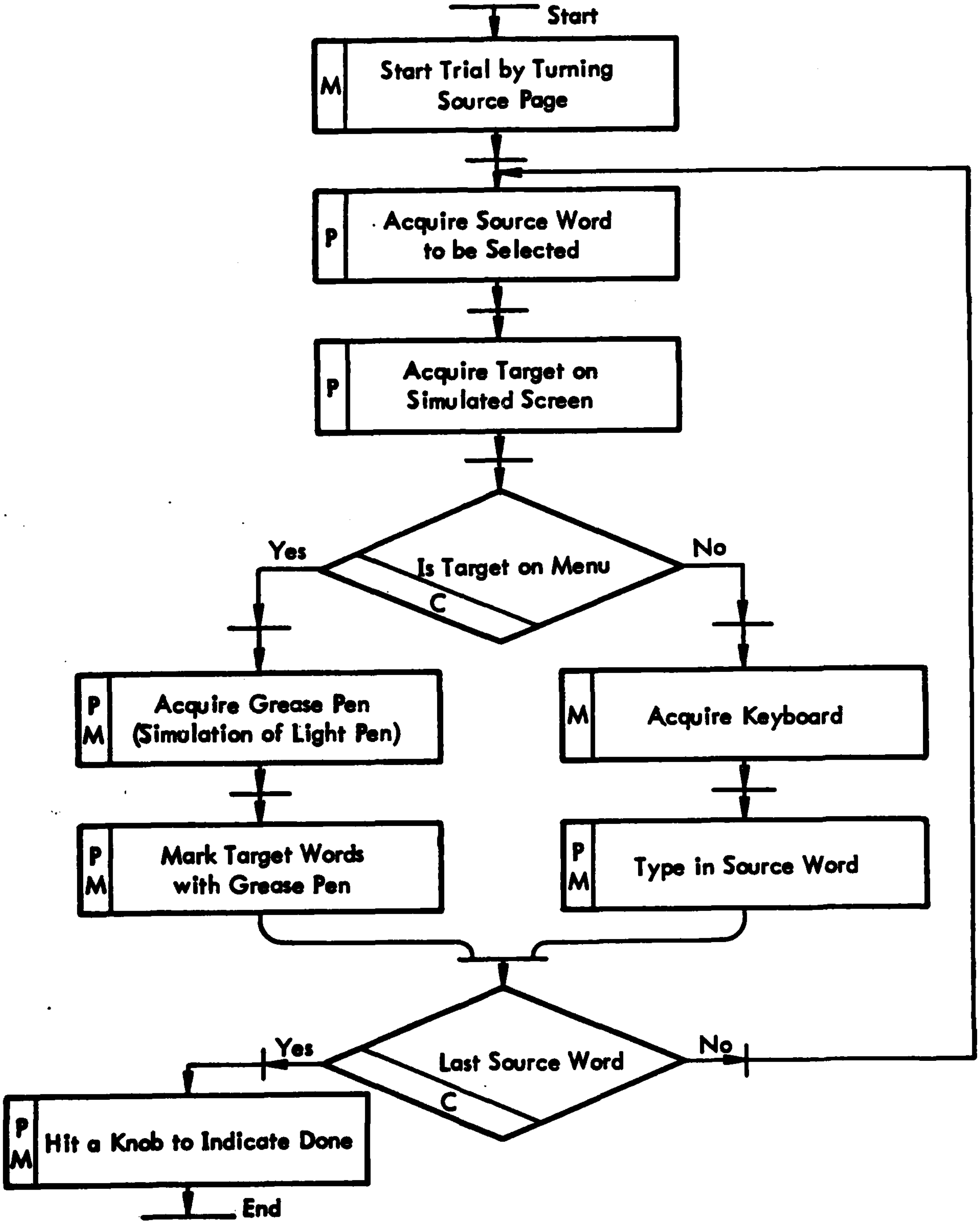


Figure B.5 Menu selection using light pen and keyboard.

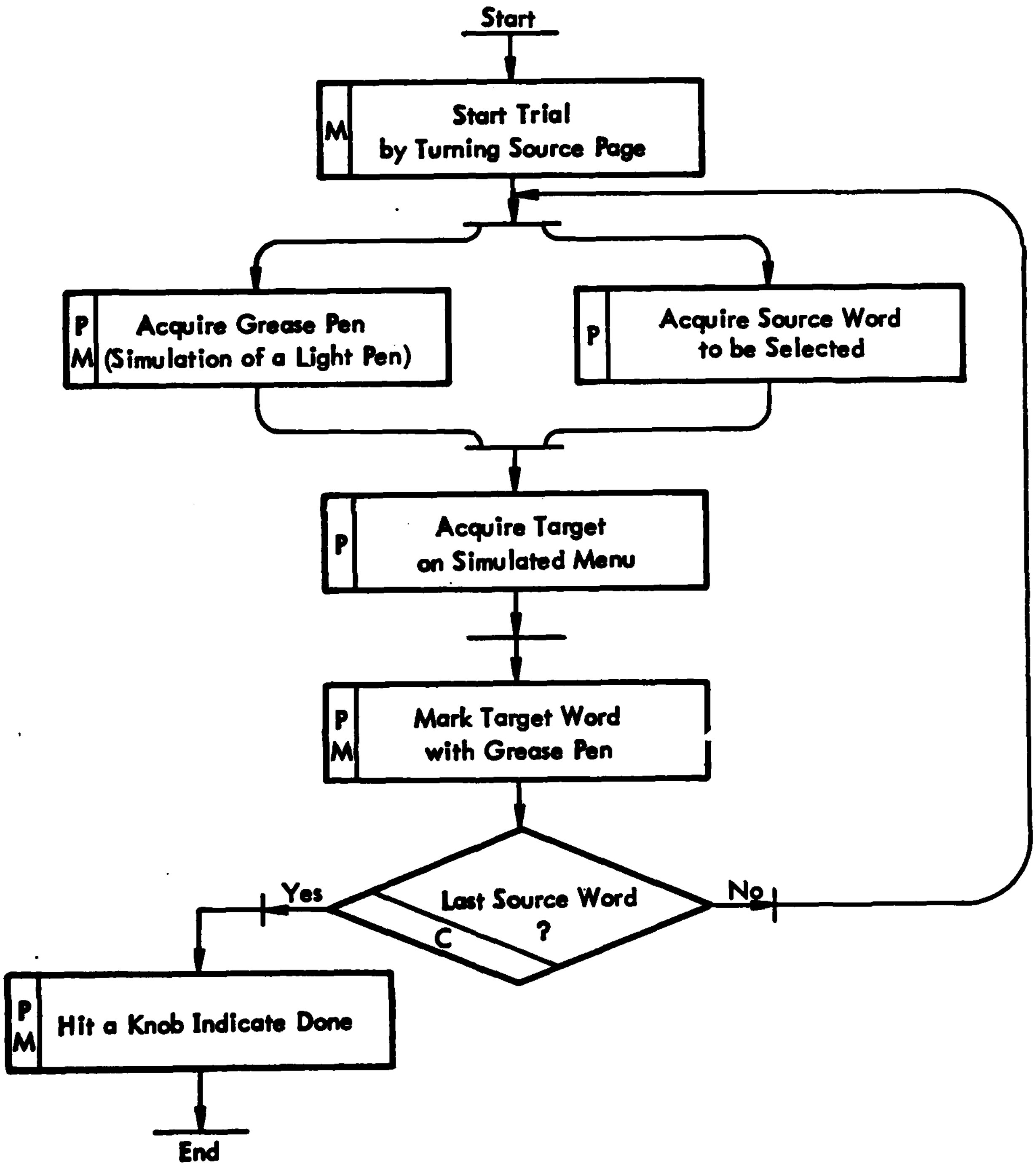


Figure B.6 Menu selection using light pen.

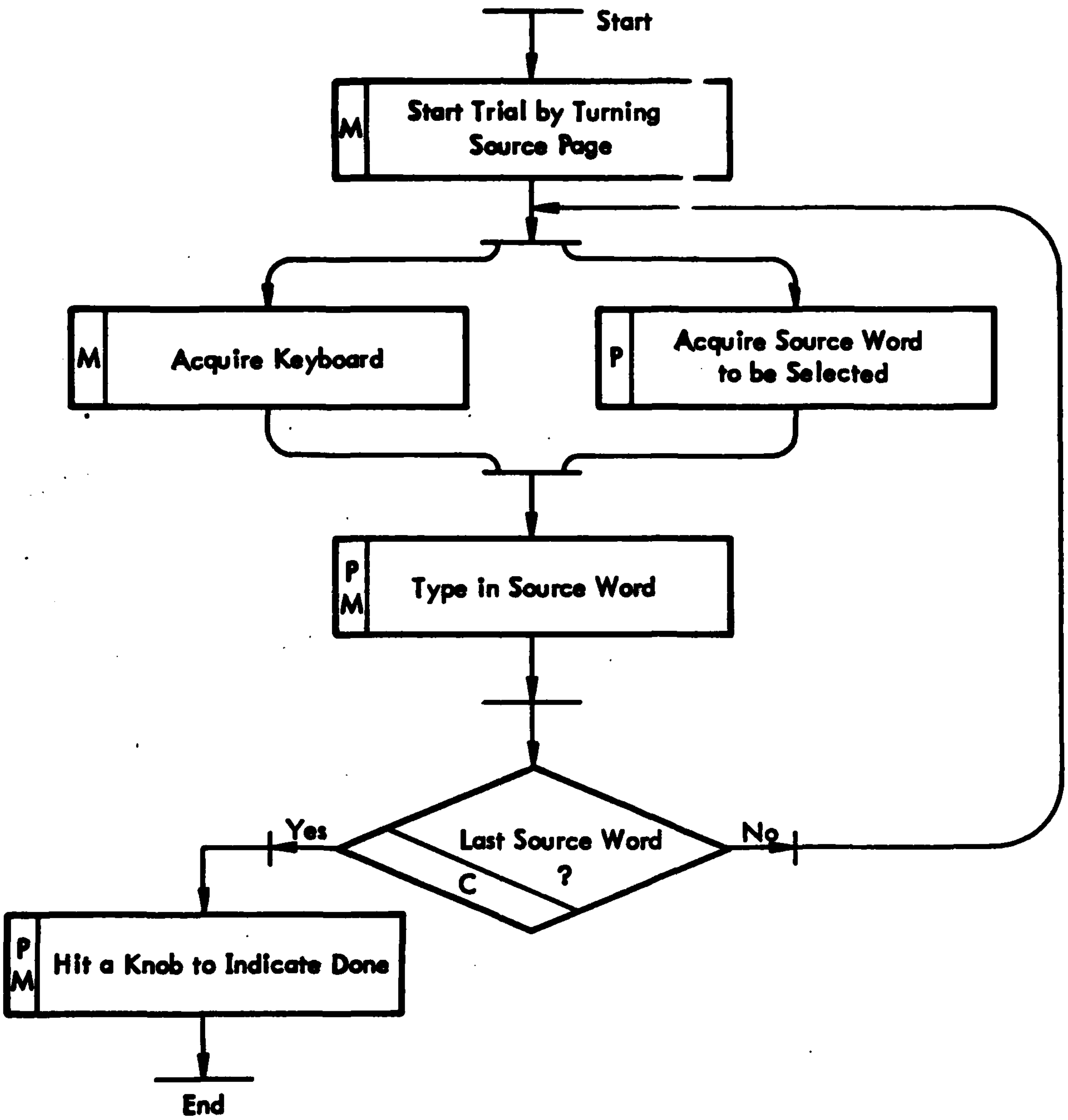


Figure B.7 Menu selection using keyboard only.

In the mixed-device task, as shown in the technique diagram (Figure B.7), the subject needs to determine whether the targets are on the menu before obtaining the appropriate device. If so, he then obtains the grease pen and marks the target on the menu. If the target is not on the menu, the subject obtains the keyboard and types in the target word. The subject might have to repeat this process for all three target words. An interaction technique of this nature imposes heavy perceptual, motor, and cognitive loads on the user.

Other variables evaluated are: the arrangement and size of the menu, subject's typing ability and sex, and the position of the keyboard in relation to the subject. Input time and number of errors were taken to be the performance measures of each device. Input time is elapsed time between the start of an input task and its completion. Error rates were scored as follows:

1) For light pen picking from the menu, the number of errors made is the sum of wrongly selected words and words which appeared on the menu but were not found.

2) For picking with light pen and typing when necessary, errors are the sum of wrongly selected words, words which appear on the menu but were typed in instead, and typing errors.

3) For selection by typing only, the only errors are typing errors.

Analysis of the performance measures (input rate and accuracy) relative to the variables evaluated showed only menu size and typing skill to be significant:

1) The size of the menu affects the selection rate and accuracy for techniques which involve picking with a light pen from a menu. The larger the menu is, the longer the input time and the higher the error rate will be to pick with a light pen.

2) Skilled typists have a statistically significantly faster input rate for selection techniques which involve mostly typing, but the practical effect in terms of input times were small (no data given for this).

The experiment also showed that selection using the light pen only is slightly faster than using the keyboard; and the light pen only task has a lower error-rate over the keyboard only task by a ratio of 1:8. This suggests the use of a spelling corrector to reduce the error rate of a keyboard entry oriented system, as in [FIEL78].

B.3. A Comparison of Selection Devices (English, et al.)

ENGL67 English, W.K., D.C. Engelbart and M.L. Berman, "Display-Selection Techniques for Text Manipulation," IEEE Transactions on Human Factors in Electronics HFE-8, 1 (March 1967), 5-15.

The purpose of this experiment is to compare the performance of five selection devices. The first is the light pen. The remaining four, which are locators used to move a cursor to a target, are the mouse, the Grafacon (a now obsolete mechanically-coupled tablet), the knee control, and the joystick. The experimental results indicate that for the experienced user the mouse is by far the fastest and the least error-prone selection device, while for the inexperienced user, the knee control and the light pen are marginally faster than the mouse. For all users, the mouse is more accurate, with error rates typically half of those for other devices. At the other extreme, the joystick used as either an absolute or a velocity-controlled locator fared poorest in both speed and accuracy. In spite of a few hardware and software problems which might have degraded the performance of the light pen and the joystick, the experiment was well coordinated and the procedures clearly described.

The Grafacon used in this experiment is an early form of tablet, sufficiently different in form that the results for the tablet are not valid for contemporary tablets. The knee control was made specially for this study. Up, down, left and right motions of the cursor are controlled with corresponding motions of the user's knee, which moves a lever connected to two potentiometers.

The measurements used to evaluate the devices are:

a) Time needed to select a target. This is taken to be the sum of "homing time" (called access time in the study) -- the time taken for the user to physically obtain the device, and "positioning time" (referred to as "motion time" in the study) -- the time taken for the user to move the cursor from its initial position to the target. The times are not reported separately.

b) Errors, generated when the user selects an incorrect target.

Two groups of subjects were used, an experienced and an inexperienced group. The experienced group was somewhat familiar with the interactive system and had a reasonable amount of practice on the tested devices. Subjects were asked to select two different kinds of targets, "character" targets and "word" targets. The character target was a group of 3 x 3 "X"'s, with the middle "X" representing the character target. The word target was the middle string in a group of 3 x 3 strings of 5 "X"'s each. Visual feedback was given after the subject made a selection on the display screen.

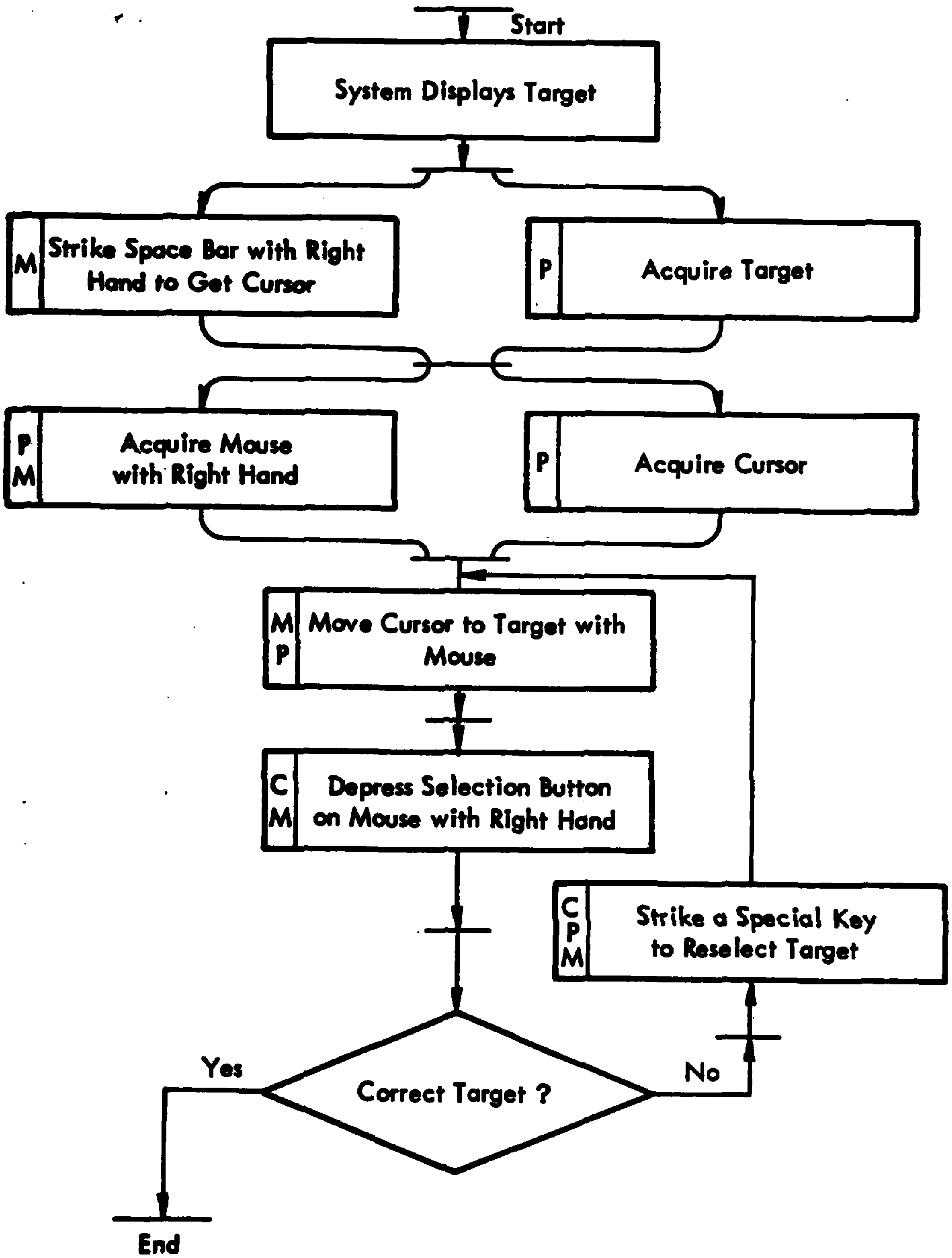


Figure B.8 Selection using a mouse.

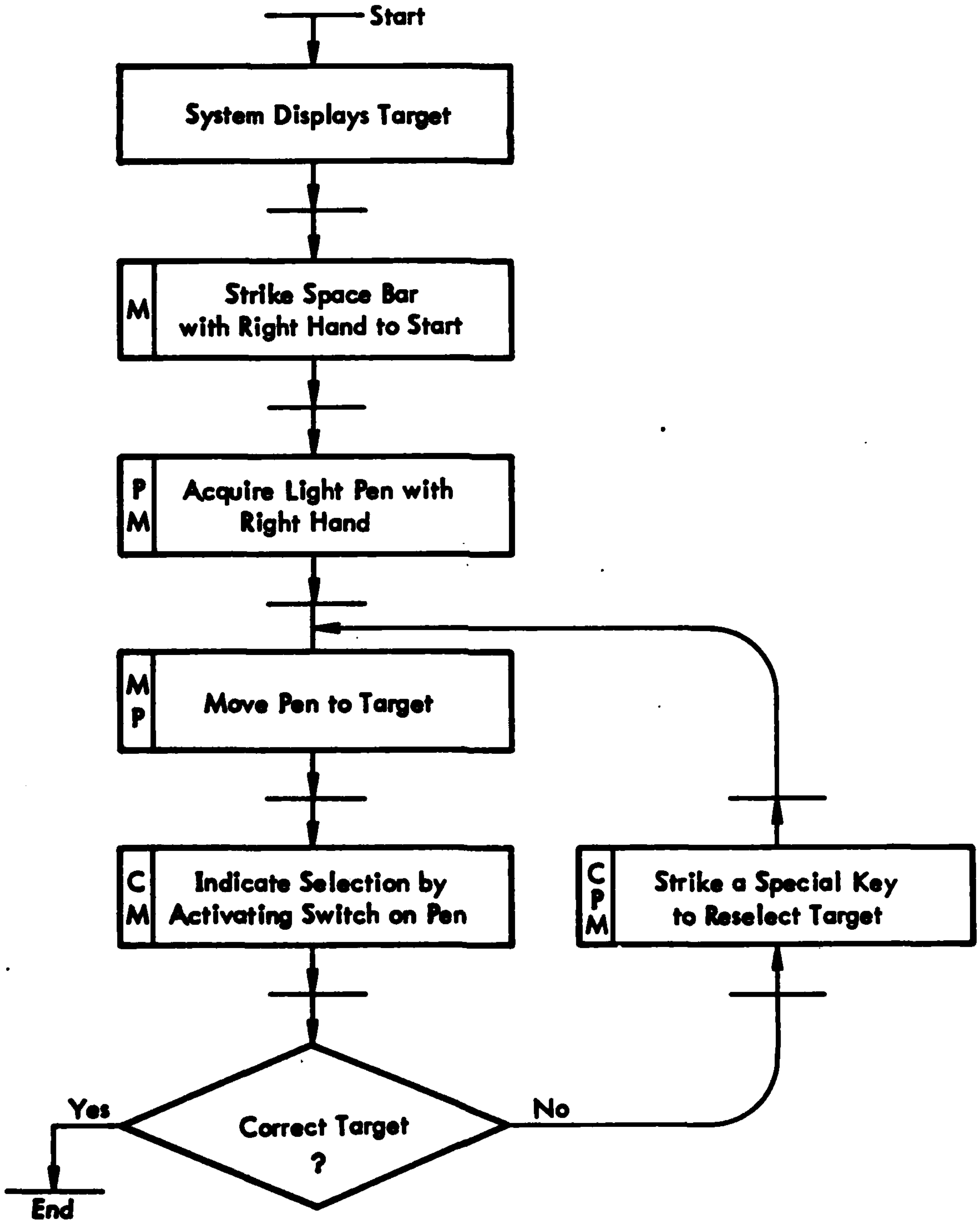


Figure B.9 Selection using a light pen.

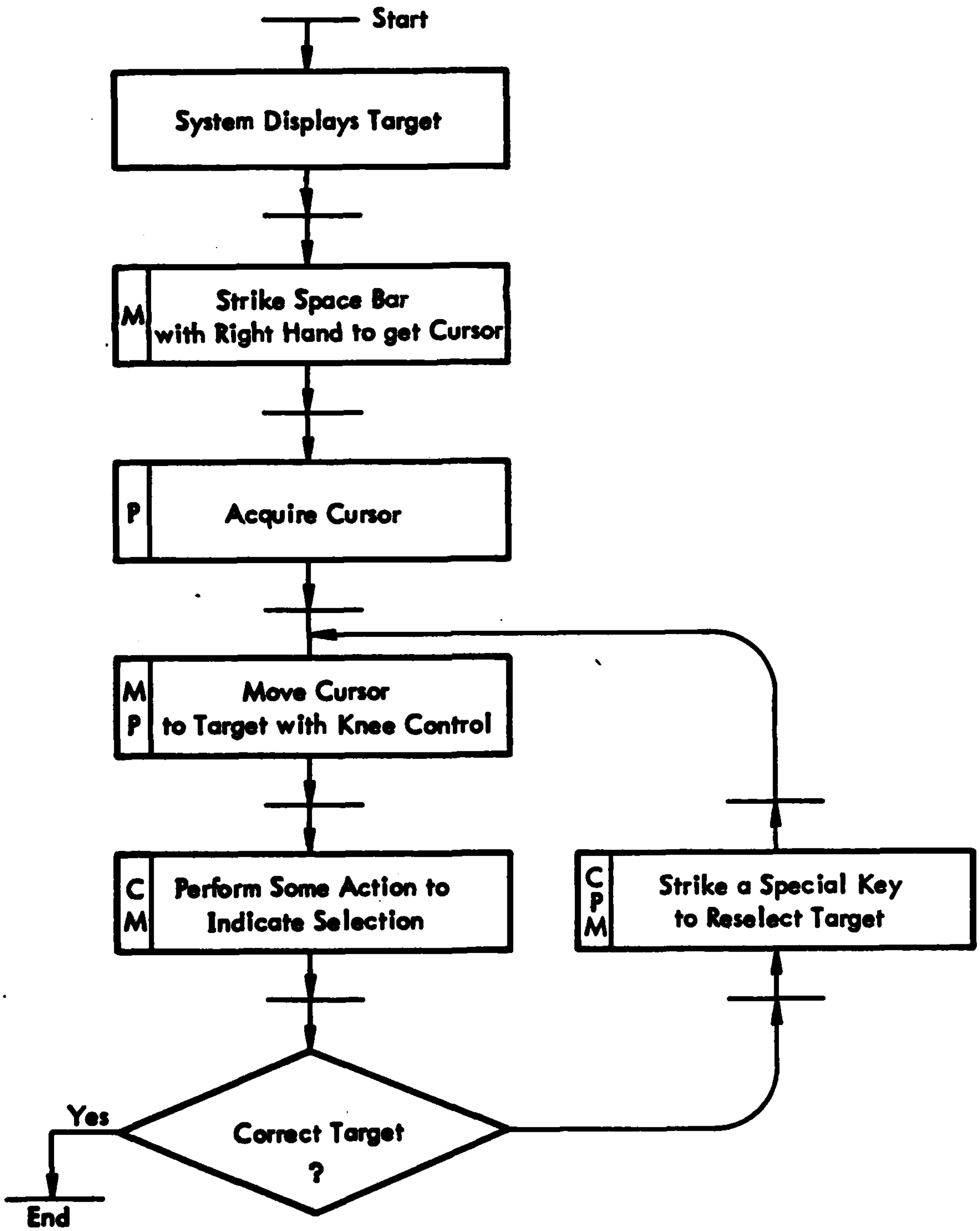


Figure B.10 Selection using a knee control.

The experiment starts with the target al.eady on the display, as shown in the interaction technique diagrams for the various devices (Figures B.8 to B.10). As soon as the experiment starts, the subject visually acquires the target, hits the space bar with the right hand to start the timer and to cause the cursor to appear on the screen. After doing so, the subject visually acquires the cursor and reaches for the interaction device.

Note that the light pen technique diagram does not have the perceptual step of acquiring the cursor; this step is not necessary in the light pen case. For the knee control, there is virtually no need to physically obtain the device because the device is always within touch of the subject's knees. After the cursor, the device, and the target are acquired, the subject moves the cursor to the target, with his right hand controlling the device. For the light pen, the pen itself, rather than the cursor, is moved to the target. After the cursor or the pen is on the target, the subject indicates selection by depressing a button associated with the device being used. (The button associated with the knee control is not described.) Following the button depression, "CORRECT" is displayed if the subject selects the right target; otherwise, the wrongly selected target is underlined and a bell signal given. In order to resume selection, the subject has to strike a special "Command Delete" key with his left hand. The subject has to then relocate the cursor and reselect the target. Essentially, the task enters a loop until the subject makes a correct selection.

For experienced users, with whom only the mouse, the Grafacon tablet, the light pen, and the absolute-position joystick were tested, the results indicate that the mouse is both faster and more accurate than the other devices tested. The ordering for seclecting either the character or word target was the same: mouse (1.68 secs. word, 1.93 secs. character), light pen (1.81, 2.13), Grafacon tablet (1.92, 2.43), absolute joystick (1.99, 2.87). Error rates in character mode ranged from 9.5% for the mouse up to 27.8% for the joystick, and in word mode from 9.3% for the mouse up to 20.6% for the light pen.

The inexperienced users, however, use the knee control and the light pen marginally faster than the mouse, though the mouse remains the most accurate device tested. In the character selection mode, the ordering was: knee control (2.36 secs.), light pen (2.43), mouse (2.62), Grafacon tablet (3.26), absolute joystick (3.29), velocity joystick (5.22).

In all cases the joysticks, especially the velocity-controlled joystick, performs unfavorably as a selection device. In the worst case, the mouse is faster than the velocity-controlled joystick by a ratio of 1:2 with a corresponding error rate ratio of 1:3. It was found that there was really no significant correlation between the starting position of the cursor, the position of the target, and the performance of a device, in defiance of Fitts' law. This may be because the actual movement time was much less than the other time measurements (hit space bar, acquire device, target, and cursor, then depress selection button) included in the recorded time. The initial cursor position was apparently randomized. However, times were higher for small (character) targets than for large (word) targets, in accord with Fitts' law.

Some important observations are made in the study:

1) The experimenters comment that although the light pen requires less practice because of its naturalness as a pointing device, using the device can cause fatigue after a period of use.

2) The knee control was not developed soon enough to be tested by the experienced users. The device was found to be the fastest device for the inexperienced users because there is practically no homing time to physically obtain the device. Several tests by experienced users indicated that the knee control appeared both slower and less accurate than the mouse and the light pen. This is not unexpected, as fine motor control at the knee is less than with hand and fingers. It is also possible that the knee control's C/D ratio (defined in Section 4.2) amplified the knee movements too much, or too little.

3) There were some obvious defects in some of the devices used: the mount of the light pen was somewhat clumsy so that the subject had to reposition the pen on its mounting before he could return to the keyboard for the next target selection. The select buttons on both the Grafacon and the joystick tended to move the cursor when depressed, increasing their error rates. The C/D ratio of the joystick used was 1:4. Also, there was too much dead space around the center position of the stick. This might have accounted for its lack of fine control.

4) The outputs from the Grafacon tablet are polar coordinates about the pivot point of a movable arm whose tip indicates a position. These outputs were interpreted by the system as rectangular coordinates. Hence, a user wanting to trace in a straight line across the display screen must move his hand in an arc on the tablet. This suggests difficulties with hand-eye coordination, but the experimenters "found no evidence that the user was aware of the distortion." However, the Grafacon was not the top performer.

5) The mouse and tablet had a C/D ratio of 1:2.

The experiment was well designed and conducted. Unfortunately no tests of statistical significance were applied to the data. From the interaction diagrams of the techniques, we can see that the experimental procedures were well-defined in the paper, except for the case of the knee control where the explicit action required of the subject to make a selection was not specified.

Another important factor that was not mentioned in the study is whether all the subjects selected were right-handed. The design of the experiment required the subject to hit the space bar with his right hand to get the cursor on the screen, to obtain the device with the right hand, and to manipulate the movement of the cursor with the device using his right hand. If some left-handed persons were chosen as subjects, the results of the experiment would be somewhat biased. Also, as Ramsey

observes [RAMS78], the need to hit the space bar before using a device could degrade performance with the hand-operated devices, due to the need to move from the space bar to the device.

B.4. Valuation and Selection Techniques (Fields, et al.)

FIEL78 Fields, A.G., R.E. Maisano and C.F. Marshall, A Comparative Analysis of Methods for Tactical Data Entry, (September 1978), Army Research Institute for the Behavioral and Social Sciences (PERI-OS) 5001 Eisenhower Avenue, Alexandria, Virginia 22333.

This experiment evaluates four methods of entering data in terms of speed and accuracy for naive users. The data, which consists of descriptions of military objects, map coordinates, dates, and cardinal numbers taken from written intelligence reports, is in part numeric and in part words selected from a predefined set of terms. The different input techniques, shown in Figures B.11 through B.14 are:

1) Typing numeric type data and labels (i.e., numeric codes) of items onto a displayed form (Label Type-In).

2) Typing as in 1, but with error correction attempted by the computer (Label Type-In with error correction).

3) Menu selection -- selecting the desired object name from a logically or alphanumerically ordered menu (of 40 or fewer items) using a track ball. Typing is required to input numeric data.

4) Typing only sufficient digits or characters to uniquely identify a term, using either the appropriate numeric code or the term itself. The computer automatically completes the entry (Label Type-In with auto completion).

Menu selection with a track ball was the most accurate input technique, and tied in speed performance with Label Type-in. The results suggest that menu selection with occasional typing is a viable interaction technique for text entry, if the set from which the data is selected is and small.

Thirty-two subjects, none having experience with the techniques, were selected. While 80% of the subjects claimed some typing skill, their skill level is unclear. The subjects were divided into four groups, one for each input technique. Each subject received eleven text messages, in free-format decription, of a simulated battlefield situation. The first 3 messages were used as practice; performance with the last eight was measured.

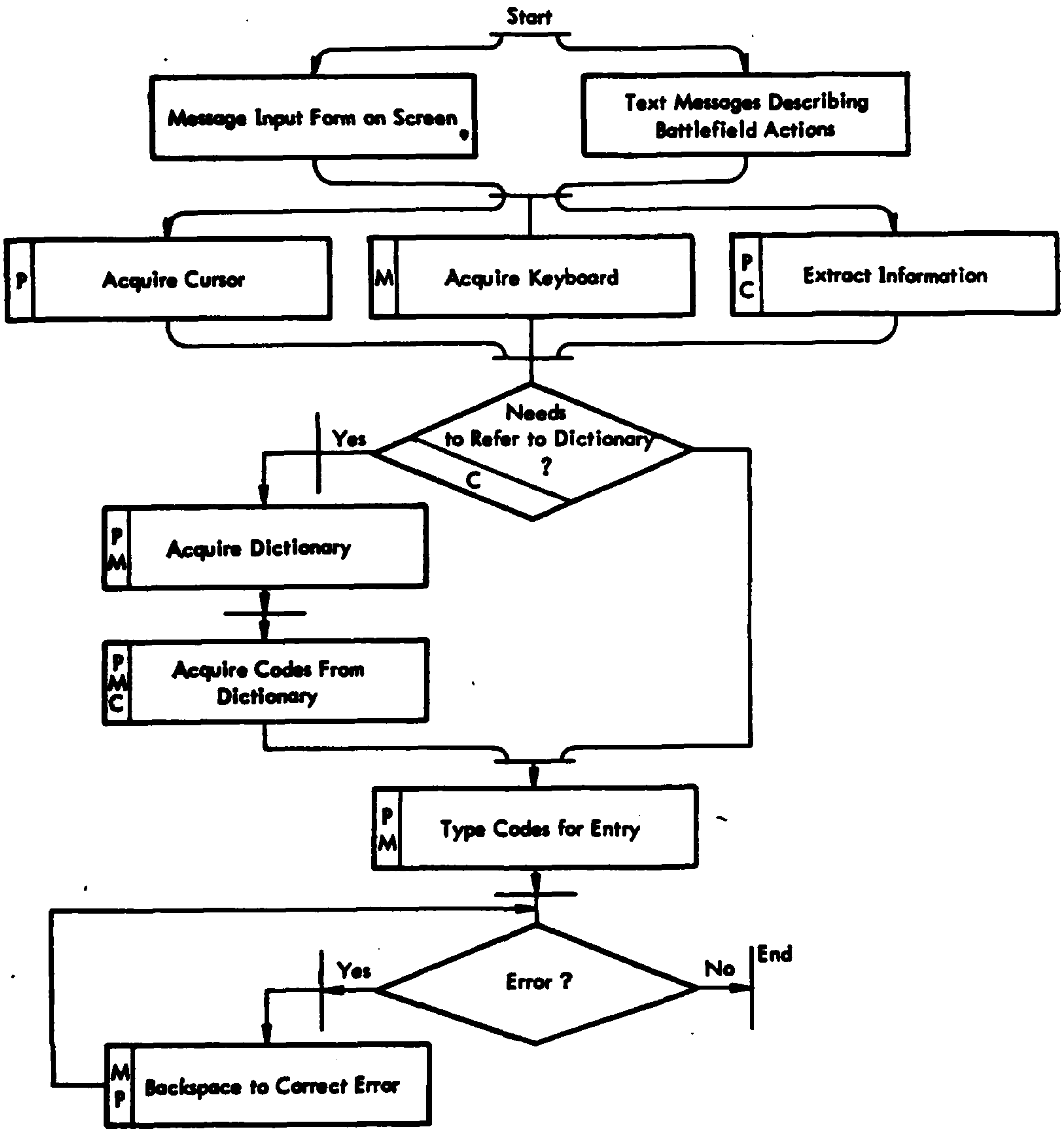


Figure B.11 Label type-in.

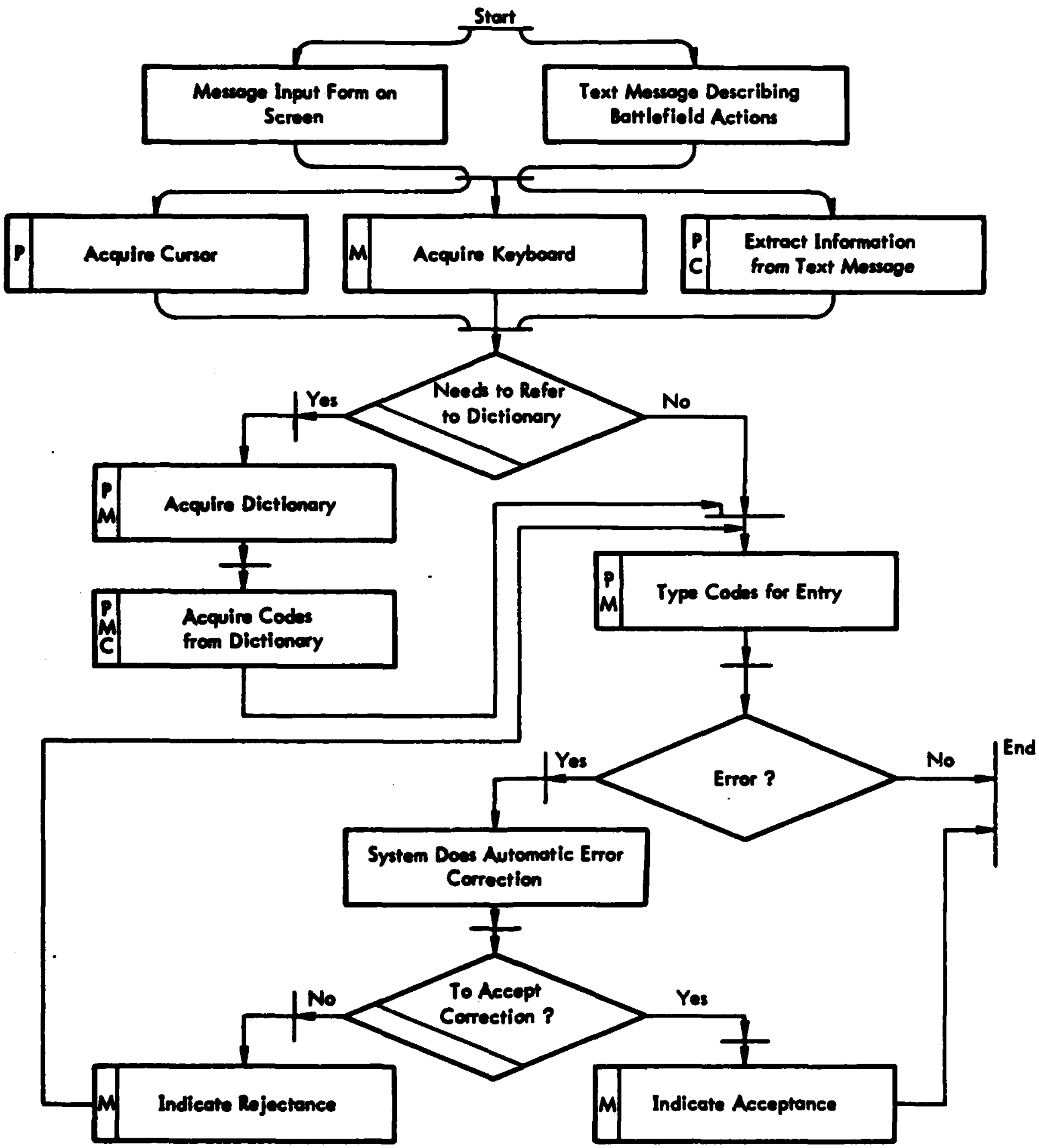


Figure B.12 Label type-in with error correction.

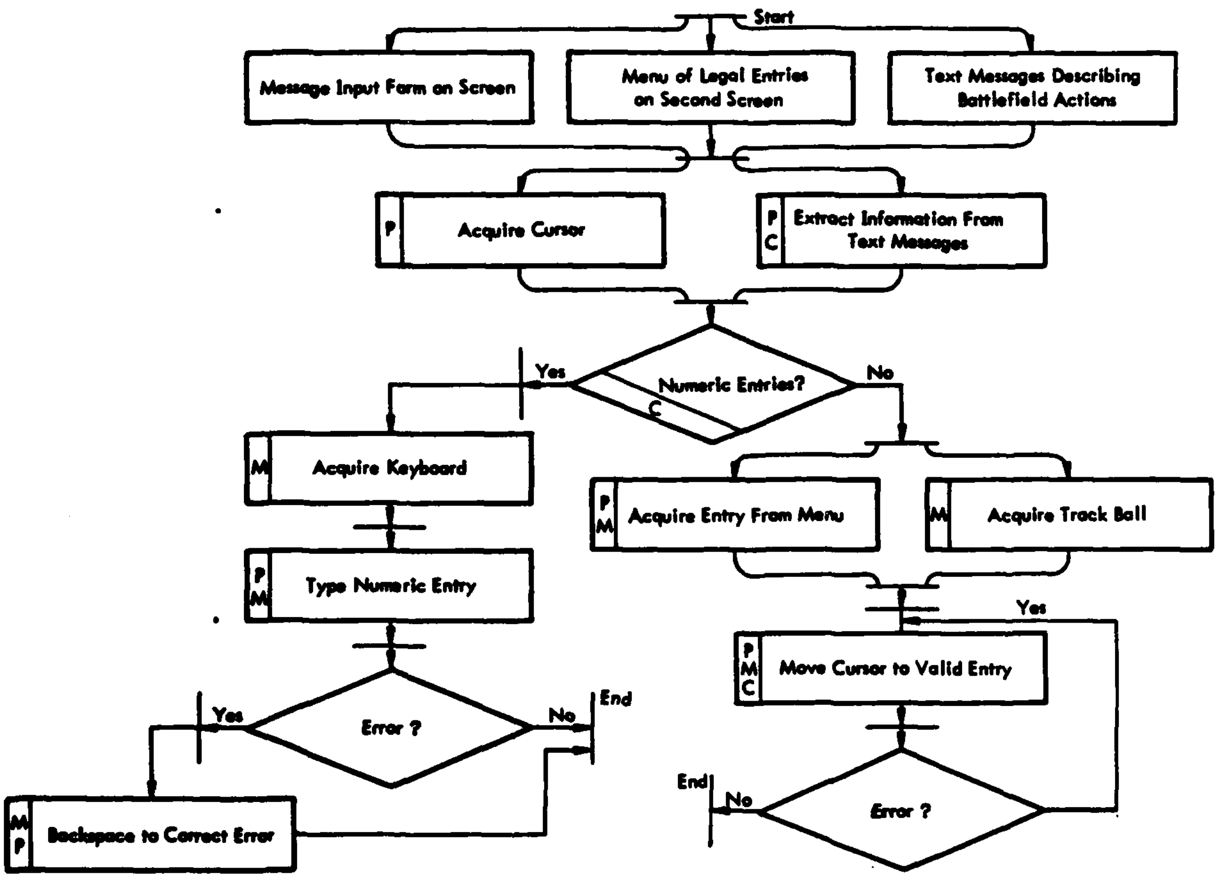


Figure B.13 Menu selection using trackball.

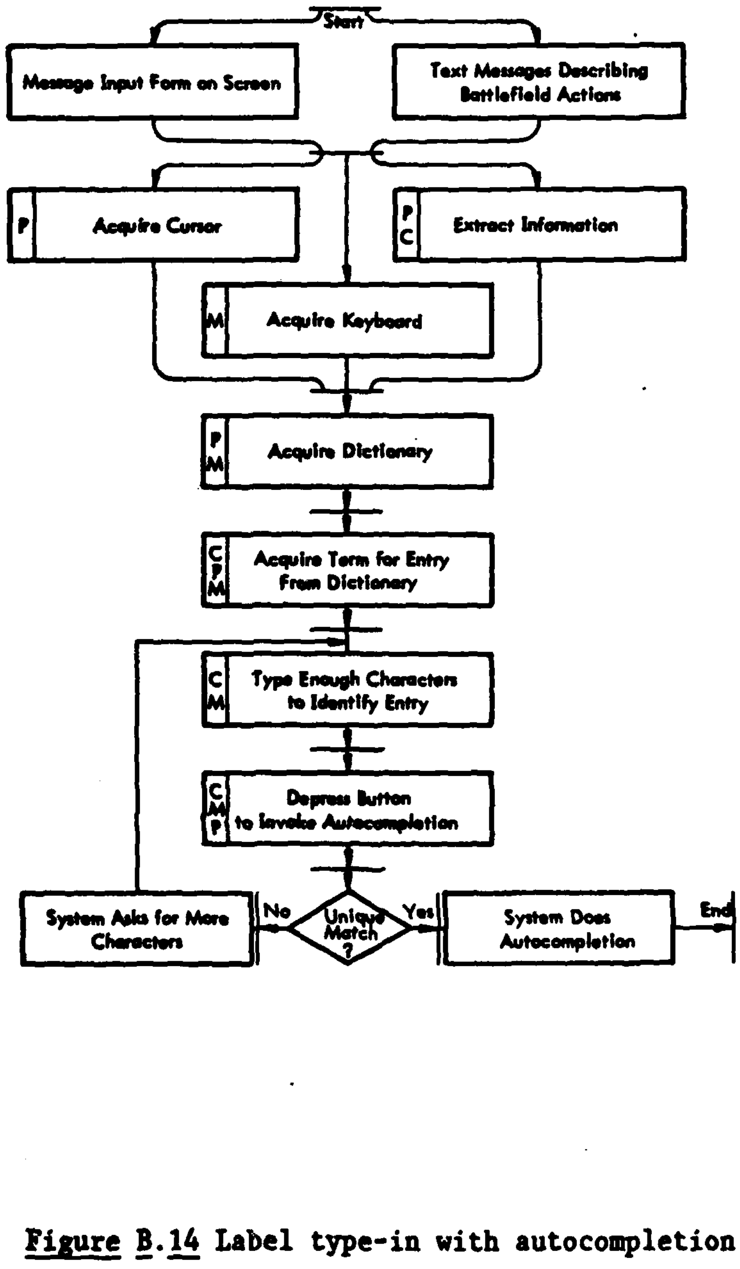


Figure B.14 Label type-in with autocompletion.

The task was to extract required information to fill a displayed form which showed what information was required and the form in which the data was to be entered. The information was entered either as numeric codes or as words, depending on the input technique. A dictionary containing the numeric codes and their English definitions, cross-referenced to the items in the input format, was provided. The menu, when used, was displayed on a second CRT next to the one displaying the form.

For the Label Type-In technique, numeric codes not in the dictionary were rejected by the computer. The user would then backspace and retype the code before being allowed to go on.

Label Type-In with error correction was the same as Label Type-In except that the computer would attempt to correct typing errors. If the computer found a match to what it assumed the correction to be, it would print out an error message along with the correction. The subject then either signals acceptance of the correction or retypes the entry. If the computer is unable to suggest a correction, the subject retypes the entry.

For menu selection, the subject is either prompted to type numerical data or to use a trackball to select from a menu of possible words. Invalid entries must be corrected before the user can proceed to the next entry.

The time taken to input information extracted from each message was recorded for each input technique. Time ranking of the techniques is: Label Type-In (396 seconds per message), Menu Selection using a Trackball (396 secs.), Label Type-In with Error Correction (397 secs.), and Label Type-In (413 secs.).with Autocompletion (413 secs.). These mean times are too close to indicate any signficant difference. The accuracy ranking of the techniques were ranked on two criteria: the mean number of errors per message and the number of participants who made the fewest errors using a particular technique. The ranking was the same for both criteria: Menu Selection using a Trackball ranked first, Label Type-In with Error Correction second, then Label Type-In, and finally Label Type-In with Auto-completion. The number of errors were 2.64, 3.36, 3.77 and 4.39.

The time and accuracy rankings suggest that menu selection is the best input technique for the task studied because it offers accuracy without sacrificing input rates. However, one would hesitate to generalize these results because the overall task is extremely specialized and because the time and error rankings reflect the subjects' ability to extract and interpret the specific data used, not just the virtues of the input techniques. Furthermore, the experimenters point out that even after eleven trials (3 practice + 8 real) per subject, performances were still improving. Who knows what the relative rankings would be with more experience? The present conclusions are valid only for naive users.

Entry by just typing the codes did not appear to be significantly slower or more error-prone than with typing with the error corrector or typing with autocompletion. It might be that the users were inexperienced in using these features. The experimenters reported user complaints about the autocompletion feature as being confusing and difficult to use. The corrector only decreased error rates by 11% compared to typing without the corrector, suggesting that this feature might be most useful for users of very limited typing skill or very low spelling ability.

B.5. Chord Keyboard Command Entry Method (Gallo and Levine)

GALL66 Gallo, P.S. and J.R. Levine, Human Factors in the Design of an Observer's Keyset, U.S. Navy Electronics Laboratory, San Diego, California (October 1966).

The purpose of this pilot study is to compare the input rates and the accuracy of two modes (the manual and the automatic) of command entry using a chord keyboard. On a chord keyboard, subjects enter the desired command by depressing the appropriate patterns of keys. As a result of a pilot study done before the experiments conducted in this research, it was found that command entry on a chord keyboard in the manual mode of command-entry is much slower and more error-prone than in the automatic mode. In the study subjects entered one of the 26 alternatives coded in five-bit patterns by pressing the appropriate keys using the five-bit keyset. In the automatic mode, releasing all keys automatically entered the command; in the manual mode, only striking the entry bar, which is similar to a space bar, would enter the message. Even though no experimental results were given, the authors strongly stated that the use of the entry bar greatly increased the error rates and sharply decreased the input rates.

It is quite obvious that using the entry bar to indicate when a command is entered would be redundant for a system that has preknowledge of the incoming data as five-bit codes. These types of studies, however, are good attempts at isolating and giving recommendations on different design considerations for particular applications.

B.6. A Comparison of Selection Techniques (Goodwin)

GOOD75 Goodwin, N.C., "Cursor Positioning on an Electronic Display using light pen, light gun, or Keyboard for Three Basic Tasks," Human Factors 17, 3 (June, 1975), 289-295.

This experiment compares the performance of the light pen, the light gun, (a variant of the light pen using a pistol grip) and step keys with cursor match for selection on an alphanumeric display. The

only measurement considered was the time taken to select a target character on the display screen, and then to type a replacement character on the keyboard. Experimental results showed no significant difference between the light pen and the light gun, but both devices were faster than the cursor positioning keys. In the extreme case, in which the subject moves the cursor large distances over the display, step keys were found to be four times slower. However, this result is biased because the step key technique used forces cursor movement to be line-by-line, rather than in arbitrary up-down-left-right direction.

Six subjects were used, three of whom had previous experience with the particular device and setup used in the experiment. The inexperienced subjects were given practice sessions with the devices before the experiment.

Subjects were asked to perform three basic tasks: arbitrary cursor positioning, sequential cursor positioning and proofreading. The arbitrary cursor positioning task was to move the cursor to ten randomly displayed digits in numerical order from 0 to 9, and to replace each with an "X". The sequential cursor positioning task was to replace ten randomly displayed target characters with an "X", moving from the top to the bottom of the display. In both cases, the display screen consisted of rows of dashes plus the ten target digits. The proofreading task required the subjects to replace ten randomly displayed single-letter errors with an "X". The test consisted of three parts, one for each device. Each part consisted of three sections, one for each positioning task, generating a total of nine experimental conditions. Each condition was repeated three times.

The experiment starts with a display of instructions for each positioning task. Each trial for the task begins with the test material on the display screen, as shown in the technique diagrams for the devices tested (Figures B.15 and B.16). As soon as the trial begins, the subject acquires the target, acquires the cursor, and then obtains the particular device tested in the trial. Then the subject moves the light pen or the light gun to the target; for the keyboard, the subject moves the cursor to the target by using the step keys on the keyboard. The light pen and the light gun trials involve an extra step of activating a switch on the device to cause the cursor to move to the target. When the cursor is on the target, the subject overtypes it with an "X" using the keyboard. It is not clear whether the subject lays down the pointing device to switch to typing in the light pen and light gun trials. Following the overtyping, the subject sends a message to indicate "done". If all ten targets in each trial are not changed to "X"'s, the subject repeats all the steps (except for obtaining the devices).

In all trials, the keyboard was the slowest positioning device. Contrary to the hypothesis that the light gun would be easier to aim and activate, there was not much difference in the performance between the light pen and the light gun. This might be because the tasks were too short to show any significant difference between the devices. Card, English, and Burr, however, viewed both devices as Fitts' Law devices, so both are expected to have the same maximum information processing

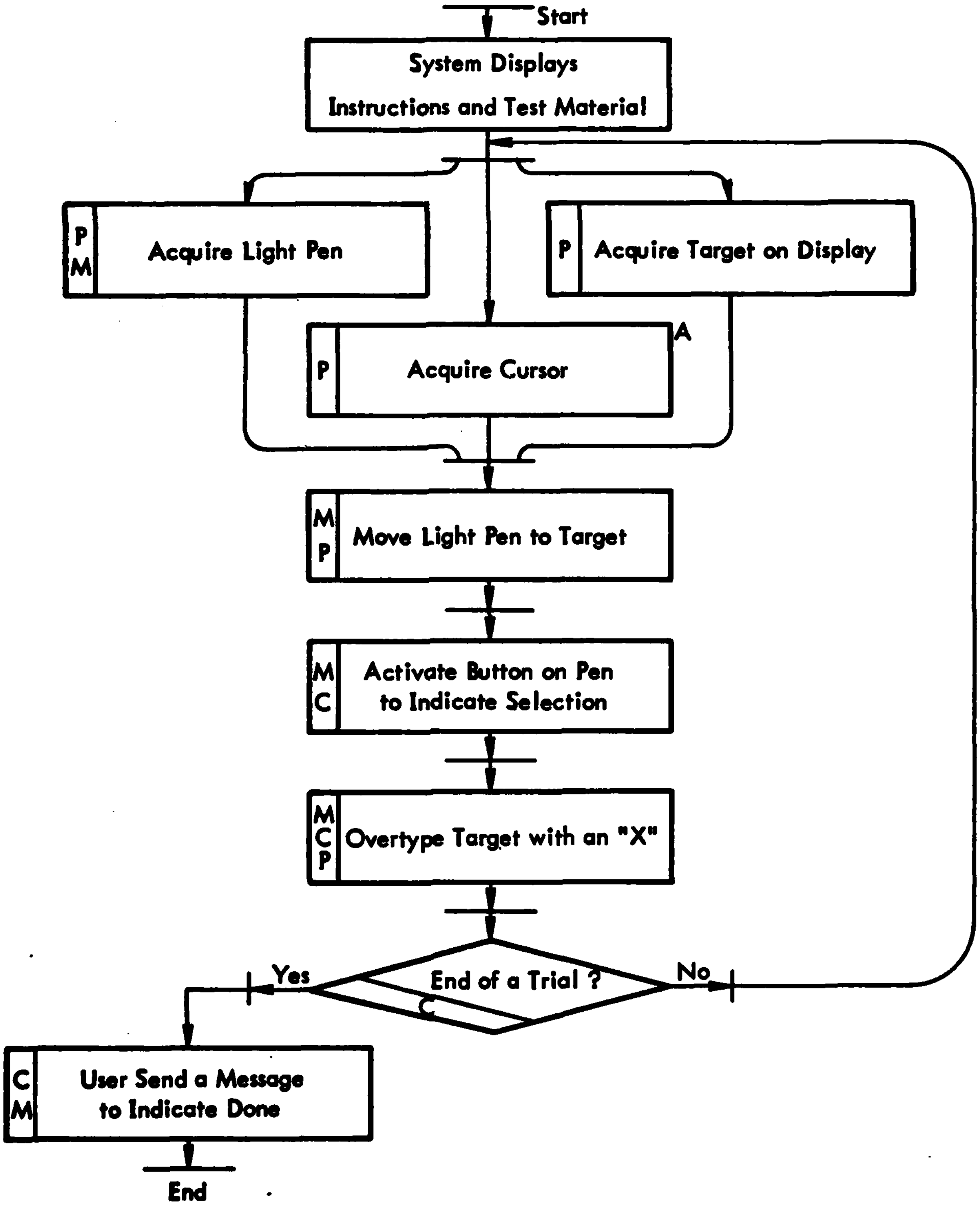


Figure B.15 Menu selection with light pen.

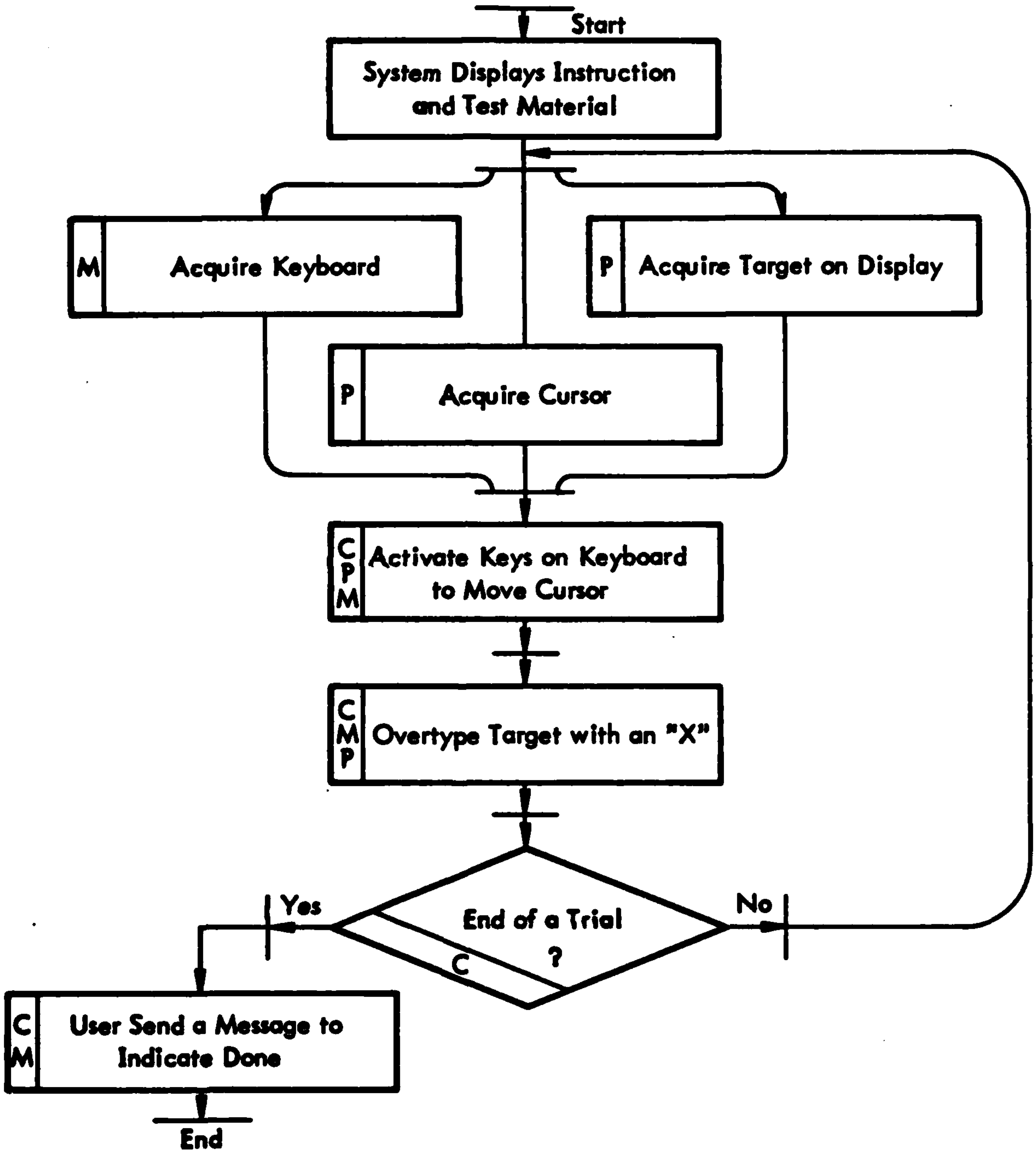


Figure B.16 Menu selection with step keys.

rate as the mouse provided the devices are optimized with respect to the C/D ratio and any other relevant variables [CARD78].

The average times for arbitrary positioning were 2.6 seconds for light gun, 3.2 for light pen, and 13.5 for step keys. There was, however, substantial improvement from the first group of ten trials to the third and last group: 3.9 to 2.7 seconds for the light pen, 3.1 to 2.3 for the light gun, and 15.7 to 11.7 for the keyboard. With more practice, further improvement would be likely--[CARD78] found that learning continued through 1,200 to 1,800 trials, yet here only 30 trials were used.

For a sequential positioning, the biggest improvement came from the keyboard, because considerably fewer kystrokes were needed. Mean times were 2.1 seconds for light pen, 2.5 for light gun, and 5.5 for keyboard. For proofreading, the times are 6.5, 6.8 and 10.6 respectively.

The keyboard had a low performance level for positioning because the particular keyboard used in the study does not allow direct up-down-left-right cursor movements. Instead, the cursor moves only in discrete steps, using combinations of carriage return, tab, shift, and repeat keys. The experiment really compares the use of a light pen and a light gun with a poorly designed keyboard. If the keyboard had permitted direct up-down-left-right cursor movements and the tasks involved alphanumeric text entry, like that of this experiment, then the keyboard would have the advantage of preserving tactile continuity, which a pointing device lacks.

B.7. Sketching Techniques (Irving, et al.)

IRVI76 Irving, G.W., J.J. Horineek, D.H. Walsch and P.Y. Chan, ODA Pilot Study II: Selection of an Interactive Graphics Control Device for Continuous Subjective Functions Applications, (Report No. 215-2), Santa Monica, California: Integrated Sciences Corp. (April 1976).

The study evaluates three sketching (pathing) techniques -- light pen with tracking cross, trackball, and joystick to first move a cursor to a random position and then do free hand sketching of an equilateral triangle and a circle. The performance measures were: the straightness of the sides of the triangle, the closeness of the drawn triangle to an equilateral triangle, and the standard deviation of sample points on the drawn circle from the centroid of the circle. The trackball was preferred over the others for the tasks described. Because the evaluation criteria taken is not very realistic (explained below) and because of the small number of subjects and replications taken, the results are not very strong or generalizable (Figures B.17(a) and (b)).

Five subjects, all inexperienced, were trained using the devices and experimental procedures. The training session was designed to bring subjects to a homogenous skill level and to identify and discourage any

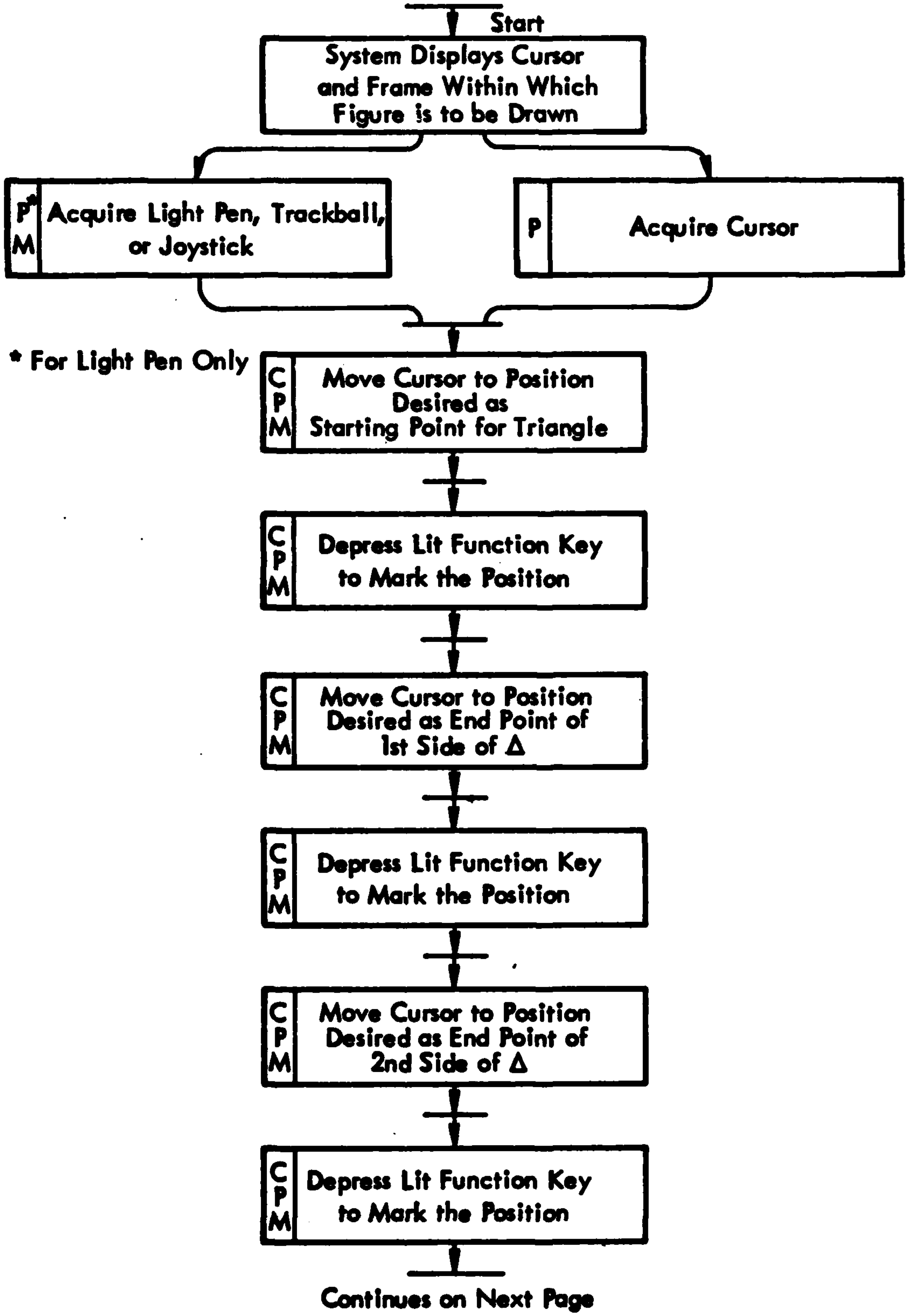


Figure B.17 (a). Sketching with light pen, trackball, or joystick.

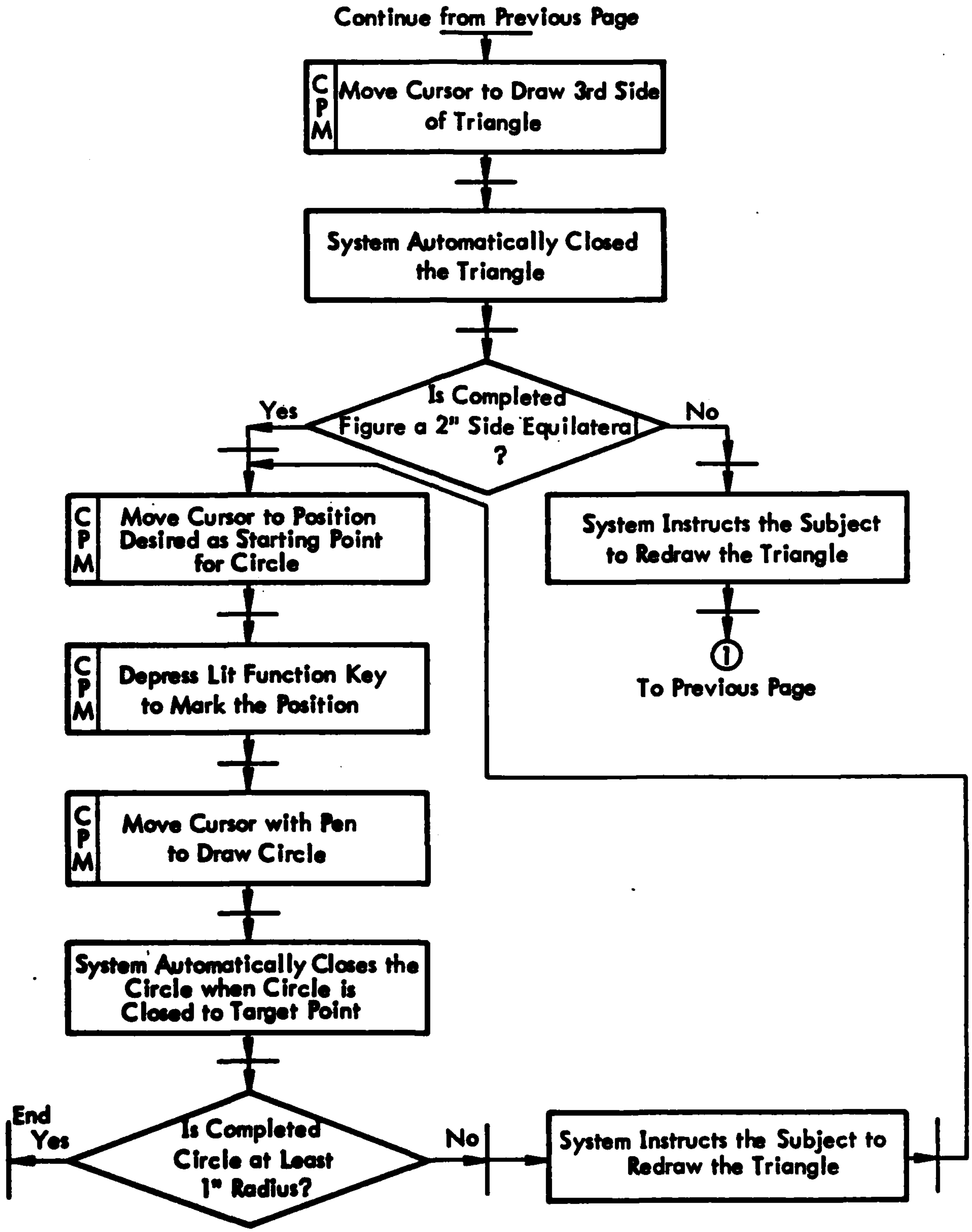


Figure B.17 (b). sketching with light pen, track-ball, or joystick.

operating strategies that subjects might have developed that could affect the results.

In each trial, the subject is asked to draw a triangle and a circle using the different devices. The subject does not use the same device for two consecutive trials. A trial begins with a display of a frame within which the figures were to be drawn, and the legend "Position Cursor." The subject acquires the device and uses the device to move the cursor to a position he desires as the first vertex of the triangle. He then depresses a function key to mark the point and draws the first side of the triangle. At the end of the first side, the function key is depressed again to mark the second vertex of the triangle. The second side is drawn and the function key is depressed to mark the third vertex. The subject draws the third side: when its end is within a specified distance from the initial vertex the system automatically closes the triangle. Each side of the triangle has to be at least 2 inches long. If the completed triangle does not satisfy the requirement, the system displays a message to instruct the subject to redraw the figure.

After drawing the triangle, the subject draws a circle. He first positions the cursor at a desired starting point and then depresses the function key. Upon doing so, he can proceed to draw the circle. The system will close the circle automatically when the cursor is within a specified distance of the starting point. The completed circle has to be at least 1 inch in radius. If not, the system displays a message and the subject has to redraw the figure.

Factors that were identified to be of significance to the performance of test tasks are the types of input device and the number of replications (the number of times the experiment is repeated). The authors concluded that the trackball yielded the best overall performance under the measurements taken. However, several observations should be made. Firstly, only five subjects were used, just three of whom performed best with the trackball. Secondly, the experiment was only repeated four times for each device with each sketching task, for 20 replications per task. Thirdly, applications which require straight lines or exact sides would allow the user to construct them geometrically. Thus the evaluation criteria used in the study are irrelevant. Fourthly, because the tasks involved only free-hand sketching, we cannot apply the results to tracing (digitizing) already-displayed lines. Hence, we can draw no generalization from this study because of the small population of subjects, the few numbers of repetition, and the specialization of the measurements.

B.8. Locator Techniques (Mehr and Mehr)

MEHR72 Mehr, M.H. and E. Mehr, "Manual Digital Positioning in 2 Axes: A Comparison of Joystick and Trackball Controls," Proceedings of the 16th Annual Meeting of the Human Factors Society (October 1972).

The experiment compared the performance of different configurations of joystick and track ball used to move a cursor to a target, based on time and accuracy measurements. The devices tested were:

1) a velocity-control joystick,

2) a control joystick (that is, without spring-return),

3) a thumb-operated isometric velocity-control joystick mounted with a hand-held grip,

4) a miniature isometric velocity-control joystick, and

5) a 3 1/2 inch diameter trackball operated at different frictional forces and control-display ratios.

Consistently, the ranking of the devices from the best to the worst were: the trackball, the miniature isometric joystick, the thumb-operated velocity-controlled joystick mounted with a hand-held grip, the remain-in-postion joystick, and lastly, the spring-return velocity-controlled joystick. As part of the experiment, changes were made to determine the effect of C/D ratio, track ball drag (force needed to rotate ball), and joystick length. The results demonstrate that the trackball is faster than any of the joysticks. The experiment also gives useful suggestions on the C/D ratio of the devices tested. This is the only experiment which studies the effects of varying the parameters of a device.

Twenty-four subjects (four experienced) were used. The experiment starts with the target at the center of the screen and the cursor at the position of the previous trial. The subject first has to acquire the device and then position the cursor in the center of the target, a small circle about 1/16 inch in diameter. The interaction technique diagram depicts the sequence of events involved in each trial (Figure B.18). The experimenter starts each trial by saying "ready" and pressing the start button. The circle moves and the subject re-positions the cursor to the center of the circle as quickly and accurately as possible. To do so, the subject observes the new location of the target, moves the cursor to the center of the target using the particular device being tested, and finally presses a stop button. Each trial was repeated ten times to comprise a run.

After one run, the subject uses a different control configuration and repeats the trials, typically using three control devices alternately to make seven runs with each. There are no practice runs.

Measurements are of positioning time and errors. Positioning time is the time required to move the cursor from the initial position to the target position. Errors are measured in units of steps from the final cursor position to the true center of the target circle. Each step is about 1/96 of an inch in length.

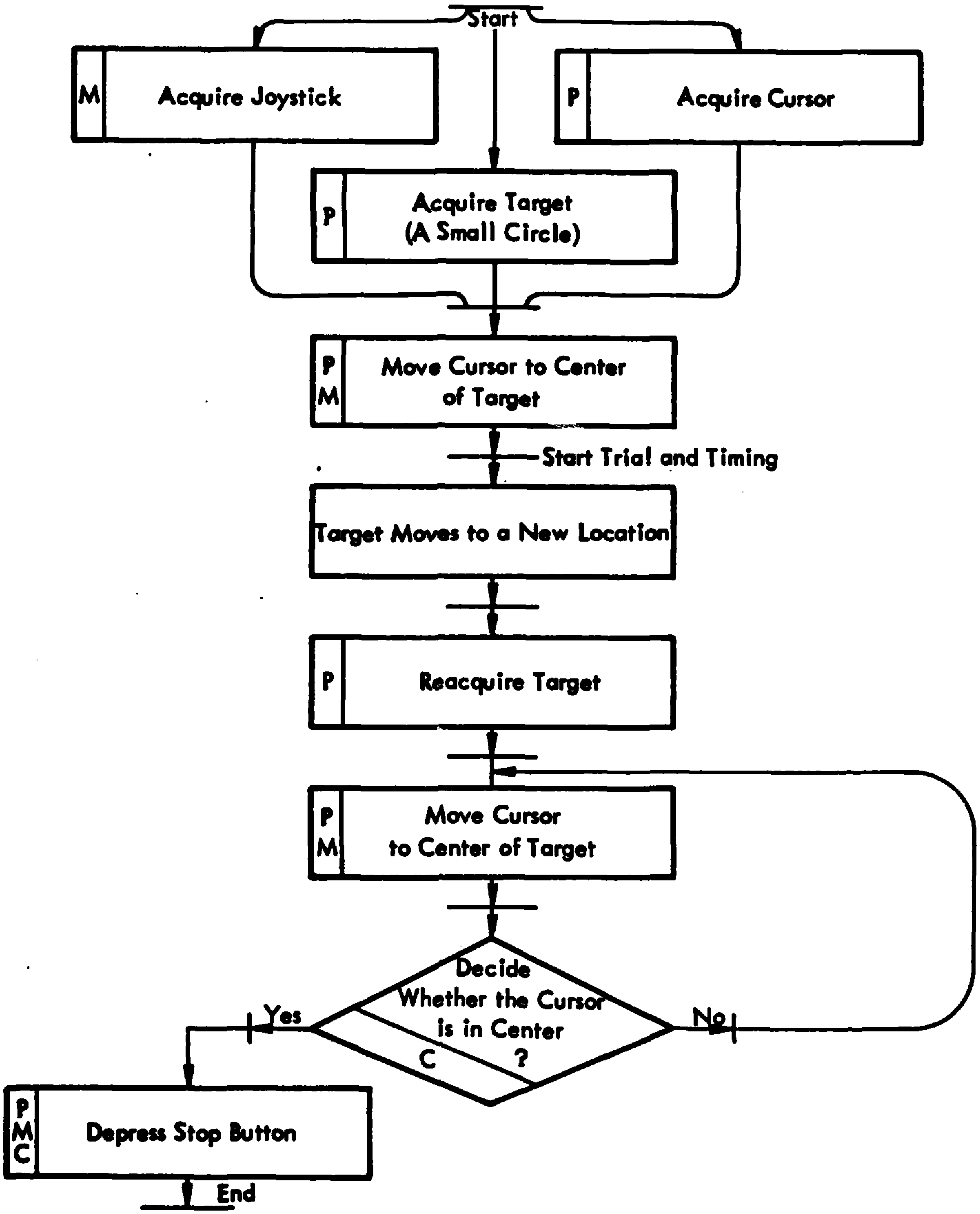


Figure B.18 Positioning using joystick and trackball. (Applies to all configurations.)

For the first run, in which the users were novices, the average positioning time with the trackball was 4 seconds; with the two isometric joysticks and position joystick, 5 seconds; and with the volocity-control joystick, 6 seconds. After 6 to 7 runs, most improvement ceased, with times ranging from 3 seconds for the trackball to 4.5 seconds for the velocity joystick. Unfortunately, these times were for sub-optimal C/D ratio, trackball drag, and joystick length.

The most important device changes were setting a trackball C/D ratio of 3:1 rather than 6:1, and decreasing the trackball drag from 50 to 35 grams (these new parameters were not obtained by exhaustive search--other values might be even better). With these changes, movements of about one-third the screen took 2.5 seconds for the trackball, 2.8 with the miniature isometric joystick, 3.0 with the hand-held isometric joystick, 3.3 with the position-control joystick, and 3.9 with the velocity-control joystick. For nearly full-screen positioning, these times were 2.8 seconds, 2.9, 3.6, 4.9, and 4.5, respectively. These times are all larger than those reported in [CARD78], but in the present experiment the target was very small, and accuracy was emphasized.

The overall results suggested that a trackball operating at C/D = 3:1 is the best for positioning and selecting tasks for both new and skilled users. If a joystick configuration were to be used, the miniature isometric joystick would be the choice. The experiment was well conducted and designed. This is the only experiment which examines the effects of parametric changes on the device performance. Using the position of the cursor from the last trial as the initial position of the cursor of the present trial is a good design methodology, to minimize the effects of visual search time for the cursor on overall positioning time.

B.9. Command Selection Techniques (Morrill, et al.)

MORR68 Morrill, C.S., N.C. Goodwin and S.L. Smith, "User Input Mode and Computer Aided Instruction," Human Factors 10, 3 (1968), 225-232.

The experiment compares ease of learning, efficiency, and degree of accuracy between command entry with an alphanumeric keyboard and light pen picking from a menu. Keyboard entry is found to be a more effective input technique. However, the result is questionable in view of individual differences between subjects, the misassignment of subjects, and biases in the experimental procedures.

Ten skilled typists, all computer-naive, and ten unskilled typists were used as subjects. They were randomly assigned to the light pen and the keyboard groups. The experiment consisted of two sessions--an Instruction Session and a Test Session. In the Instruction Session each subject was given a page of computer generated instructions on the use of the particular input device. He also was given a file which contained information on which he was to be tested.

The instruction material consisted of sequential displays, such as the pages of a book. A subject had to go through the pages sequentially to learn the standard set of instructions; he was allowed to proceed at his own speed. Upon completion of learning, the subject answered questions on the material presented. He was allowed to return to the instructional material if he desired. The test session, which was held three days later, was a repeated session of the test exercises given in the Instruction Session. Time and error scores were recorded for both sessions.

Only 16 out of the 20 subjects completed the Instruction Session in time to continue working on the Test Session. Those who failed to finish the Instruction Session were all from the light pen group. During the Instruction Session, subjects using keyboards were significantly faster than their light pen counterparts, by a ratio of 1:2. However, there was no significant difference between the two groups in the Test Session. There were also great discrepancies between individual performances.

One would expect a fair amount of training to be required before an operator can perform well on a keyboard because of the memory load and the typing skill required. Strangely, there were no statistical differences between the skilled and unskilled typists on their keyboard-entry performance. This finding seems to suggest that for a system of low complexity where inputs are short and simple (in the present study, the basic types of input messages are limited to only six), not much training or skill would be needed for using the keyboard as an input device.

The experiment also suggests that the learning time of the keyboard group is shorter than that of the light pen group. The experimenters attributed this to the greater familiarity of most people to a keyboard than to a light pen, and to the periodic unavailability of the instructional material from the light pen group owing to the need to display the selectable options. However, it should be noted, in this experiment, the comparison between the devices is really a comparison between hierarchical menu selection using the light pen and keyboard-entry involving construction from memory. Based upon this argument, the total score recorded in the Instruction Session is then the total of learning time and system response time; the system response time is definitely longer for the menu selection technique. The findings are, as the experimenters observed, not very reliable.

Interaction technique diagrams are not supplied for this experiment due to lack of experimental details. This indicates the design problems in experimental methodology employed. While attempting to make the interaction techniques diagram to depict the sequences of each input procedure, most of the steps were done by guessing. The authors did not provide sufficient details to indicate the particular tasks required of the subjects. Several cognitive steps involving learning the instruction material and answering questions are evident. The sample display of the instruction material in the paper suggested that the time taken to complete these long cognitive task sequences is a function of the subject's intelligence and decision-making ability as well as of the

different techniques. Also, all subjects with lower vocabulary scores were found to be assigned to the light pen group, which further confounds the result of this study. Ramsey expresses the same concerns [RAMS79].

One last interesting observation: both the keyboard and light pen groups have to acquire their devices, but the layout of the work station (as shown in Figure 1 of the paper) seems to favor the light pen group; the keyboard appeared to be further away from the display screen, destroying visual continuity.

C. Recommendations for Experimental Design

In this appendix we summarize and generalize the lessons we have learned from critiqueing the experiments in Appendix B, and offer recommendations which we hope will ensure that the results of future experiments will be more uniformally usable. This appendix is not intended to be a comprehensive guideline for the design of experiments. Rather, it is an account of certain design details that were often overlooked in the experimental designs. The recommendations fall into the following areas:

1. Selection of interaction techniques to be evaluated.
2. Identification and placement of monitoring tasks for evaluation purpose.
3. Selection of subjects.
4. Criteria for evaluation.
5. Form of reporting experimental procedures and findings.
6. Suggested areas for experiments.

C.1. Selection of Interaction Techniques to be Evaluated

The strongest experiments are those which evaluate relatively similar techniques, such as [CARD78] and [ENGL67]. This is because the cognitive, motor, and perceptual loads placed on the user are similar. On the other hand, an experiment comparing hierarchical, prompting command-entry menu selection using a light pen and free-text, non-prompting command-entry from memory using a keyboard, is a comparison between two techniques with greatly different cognitive loads: in the first case the user simply selects the next command from a menu, while in the second case the selection is from memory. An interesting experiment here would be to track users of both techniques, from the novice to the skilled user level, to determine at what point in the learning curve the keyboard entry might become faster than the menu selection, and to determine the speed differences between the two techniques when used by novice and skilled users. Notice, though, that the results would not be generalizable to other applications, which would require the learning of other sets of commands.

C.2. Identification and Placement of Monitoring Tasks

After the techniques are chosen, the designer should attempt to identify the individual cognitive, motor, and perceptual steps involved in each technique. This can best be done by making an interaction tech-

nique diagram. This precisely documents the interaction technique, and allows the user to identify explicitly whether and where to introduce monitoring steps for measurement purposes. The monitoring steps are user-performed, and are not inherent in the interaction technique. An example is in hitting the space bar to start timing of the experiment. After the injection of these steps, the designer should modify the technique diagrams to reflect such changes; thus, the technique diagrams would continue to document the experimentally-studied techniques and serve as a record of experimental details.

The designer should take extreme care of what monitoring steps are introduced into the experiment. The monitoring steps should be short and functionally minimal and should be independent of subject characteristics. Hence, those which involve long cognitive steps or which require the subjects to use a particular hand should best be avoided. It is best that no monitoring steps be present in the experiments to ensure that the findings reflect those of non-monitored techniques. Although this may sometimes be impossible, the designers should at least limit the steps to those at the beginning and the end of the techniques.

C.3. Selection of Subjects

Some researchers have reported inconsistencies between their predictions and the findings from their experiments only to find out later that the inconsistencies are partly attributable to one subject group's higher intelligence scores or educational background. Mishaps such as these can be avoided by careful screening and assigning of subjects. Some considerations in choosing subjects are dependent upon the goal of the experiment. If the experiment were to compare the ease of making selections using various selection techniques in a management information system environment, the preferable subjects would be from a class of managers rather than from a class of students. However, independent of the experimental nature are these ground rules: that the subjects chosen should have homogeneous IQ scores, uniform vocabulary scores, and compatible educational levels.

If a subject were left-handed, experimental procedures and devices should be modified to ensure the subject not be handicapped; each subject should be allowed to use his favored hand to manipulate the device. Unless the modifications can be done, it is not recommendable to include such subjects.

C.4. Criteria for Evaluation

Speed and accuracy are the only evaluation measures given in most experiments. Learning characteristics are all too often ignores. [CARD78] is an outstanding exception.

To make comparisons easier, time and accuracy should be measured in different phases. Measurements such as acquisition and positioning times and different types of errors during the learning and processing phases are useful in idenitfying the effects of certain ergonomic factors, as in [CARD78].

C.5. Form of Reporting Experimental Procedures and Findings

Most of the experiments fail to report their procedures and findings concisely or with sufficient detail to allow a critical evaluation. Firstly, there is a lack of detailed description of steps and step-sequences. Secondly, there is hardly any account of the work station layout. Thirdly, the testing material, if any, is usually not described. Finally, most experiments do not report the statistical analyses used.

The first problem can be best approached by including the interaction technique diagrams in the reports of the experiments. These techniques diagrams serve as full narration of the functional tasks, the control flows between tasks, and the necessary monitoring tasks involved in each technique/device compared. For the second problem, the experimenter can include a picture of the work station with a narrative description. In some cases, the work station layout can bias the performance of subjects. The inclusion of the picture and the description can help the reader to understand the experimental procedure and interpret the findings.

D. Interaction Devices

The purpose of this appendix is to give a non-exhaustive list of interaction devices and their general characteristics. The device descriptions, not meant to be technically oriented, are grouped according to whichever of the interaction tasks of select, position and orient, quantify, and text each device is most naturally suited. For more details on the device technology, the reader is referred to the textbooks on interactive computer graphics [FOLE81, NEWM79].

D.1. Selection Devices

There are two common selection devices: light pen and buttons. The light pen senses light on the CRT and can thus select displayed entities such as menu items. The pen's field of vision can be controlled by putting different sizes of apertures in front of the lens, or by adjusting the lens. A switch on the tip of the light pen is activated by the user (with a finger tip) to activate the pen. The light pen selects only on vector displays: on raster displays, it functions as a positioning device.

Buttons are often organized into a function keyboard, which is a bank of 16 to 32 such buttons, typically with changeable labels next to each button. The user pushes whichever button corresponds to the desired selection. The buttons on tablet cursors and the mouse are also selection devices.

The chord keyboard, another type of button device, consists of five bar-shaped keys. The user typically depresses several keys at once, like playing a piano chord. Learning the chords takes time, but a skilled user can work quite rapidly.

The speech recognizer is typically used for selection, but can be used as a text device as well. Trained to recognize a particular speaker, such systems can cope with a thousand or more words, although the modest-priced systems deal with 100 or 200 words. Each word, when spoken, must be delimited by periods of silence of .1 to .2 seconds. Because recognition accuracy is in the 95 to 99 percent range, some form of immediate feedback and a correction procedure are crucial.

D.2. Positioning and Orienting Devices

The most commonly used devices for indicating a position are the physical locators. Among them are the tablet, the mouse, the trackball, the joystick, and the touch-sensitive panel.

The tablet is the most commonly used locator. It consists of a flat surface over which a stylus or cursor is moved, the position of which is made available to the computer. The stylus typically incor-

porates a pressure-sensitive switch which closes when the user pushes down on the stylus. Most cursors have several switches which can be used to input commands. Both the pressure switch and the multiple switches are really separate button devices, physically but not necessarily logically combined with the tablet. Information is typically obtained from a tablet in one of three ways: on demand when the computer makes a request; every t units of time; and each time the cursor/stylus is moved more than some distance d. Tablet sizes go up at least to 48" by 72", with resolutions in excess of 100 units per inch.

The mouse is a hand-held device with rollers on its base. Moving the mouse across a flat surface causes the rollers to turn proportionally to the components of the motion in two orthogonal directions, thus indicating position change. While the tablet gives absolute positions, the mouse gives relative movements. This is because the mouse can be picked up, moved, and then put down without causing any change in the apparent position of the screen cursor. The mouse, like most tablet cursors, usually has several pushbuttons to input commands or other information.

The trackball, or "crystal ball," is another positioning device. It contains a ball, typically 3" to 6" in diameter, which rotates freely within its mount and is usually moved by the palm of one's hand. The ball protrudes from within a box. Typically there are several buttons on the box for command input, such as for indicating that the screen cursor has been moved to the desired position.

The joystick consists of a stick, which can be moved left or right, forward or backward, on a mount. Some have a third degree of freedom: the stick can be twisted clockwise and counter-clockwise. Very often, sets of springs are used to return the joystick to its center position. Such joysticks are called spring-return joysticks. Another type of joystick, the isometric joystick, is rigid: strain guages on the shaft measure slight motions caused by force applied to the shaft.

Joysticks are conveniently used as orienting devices. It is rather difficult to use a joystick to control directly the position of the screen cursor because a five-or-ten-fold amplification of hand movements occurs in positioning the screen cursor. Hand movements, when so amplified, can become quite jerky, and don't allow quick and fine control. Thus, the joystick is often used to control the velocity of the screen cursor's movement rather than its absolute position.

All the devices mentioned are manipulated by the user's hand, while his eyes are usually focussing on the screen. The touch panel, on the other hand, is a positioning device which allows the user to direct his full attention to the screen and to directly indicate positions on it rather than using a device to move the screen cursor to the desired location. The transparent panel is mounted across the face of the CRT display panel, the user points at a position with a finger, and the panel detects the position indicated.

D.3. Quantifying Devices

Most quantifying devices are based on the potentiometer, like the controls on a stereo set. There are both rotary potentiometers (dials) and slide potentiometers. The rotary potentiometer gives values by rotary movements while the slide potentiometer gives values by linear movements. Use of both types can help the user to associate specific functions with the specific type of quantifer.

D.4. Text Devices

The alphanumeric keyboard is the only text device. The most important functional characteristic of a keyboard device is that it creates a code (ASCII, EBCDIC, etc.), unique to each key, each time a key is depressed, and the code specifies a distinct letter or symbol.

There are many human engineering design issues which can make one keyboard preferable to another. Among these are keypad layout to minimize hand and finger movements; careful placement of especially dangerous function keys to avoid accidental activation (such as having the buffer delete key next to the carriage return); a design that gives a good feel for fast, accurate, blind typing; and a system whereby the depression of one key prevents another from being pressed except for special cases.

E. References and Bibliography

BARM66 Barmack, J.E. & Sinaiko, H.W., Human Factors Problems in Computer-Generated Graphics Displays, Institute for Defense Analysis, Research and Engineering Support Division, 400 Armn-Navy Drive, Arlington, Va., (1966) AD 636 170.

This study is a review of current practices in computer-generated graphic displays from the point of view of engineering psychology. Input devices, which are integral to man-computer systems, are also considered. Theories of cognition are examined with respect to their applicability to computer-graphics.

BENN73 Bennet, J.L., "User Interface in Interactive Systems," Annual Review of Information Sciences and Technology, Encyclopedia Britannica, 111, 7 (1973), 159-196.

BENN77 Bennett, J.L., "User-Oriented Graphics Systems for Decision Support in Unstructured Tasks," Workshop on User-Oriented Design of Interactive Graphics Systems , ACM, Pittsburgh, Pa., (October 1976), 3-13.

BOIE72 Boies, S.J., "User Behavior in an Interactive Computer System," IBM Report, (1972).

BLOO73 Bloomfield, J.R., "Experiments in Visual Search," in National Research Council, Div. of Behavioral Sciences, Visual Search: Symposium conducted at the Spring meeting, 1970, Washington, D.C.: National Academy of Sciences, 7 (1973), 150.

BRIT77 Britton, E.G., "A Methodology for the Ergonomic Design of Interactive Computer Graphics Systems," Ph.D. Dissertation, Dept. of Computer science, Univ. of North Carolina, Chapel Hill, N.C., (1977).

BRIT78 Britton, E., J. Lipscomb and M. Pique, "Making Nested Rotations Convenient for the User", proceedings SIGGRAPH 77, published as Computer Graphics 12, 3 (1978), 222-227.

Sub-image motion in a three-dimensional computer graphic system is much easier for the user to control if the subimage moves in the same direction as his hand while he manipulates the control device. The implementation of such coordinated motion of hand and sub-image implies modification of the normal procedure for calculating transformations. The convenience of such manipulation also depends on appropriate selection or design of the input device.

This paper reviews the relevant attributes of locator devices and presents an approach to their selection. It presents the mathematics of transformation nesting and "compensation" to preserve motion synchrony. Finally, it offers a case history of

PREVIOUS PAGE IS BLANK

an interactive graphic system whose human factors were improved by these techniques.

Key Words and phrases: three-dimensional computer graphics, coordinate transformations, nested rotation, ergonomics, human factors, analog input devices, man-machine interaction, kinesthetic correspondence, molecular graphics.

CAKI80 Cakir, A., D.J. Hart and T.F.M. Stewart, "Visual Display Terminals: A Manual Covering Ergonomics, Workplace Design, Health and Safety, Task Organization," Wiley-Interscience (1980), 307pp.

CARD78 Card, S.K., W.K. English and B.J. Burr, "Evaluation of Mouse, Rate-Controlled Isometric Joystick, Step Keys, and Text Keys for Text Selection of a CRT," Ergonomics, 21, 8 (August 1978), 601-613.

The experiment evaluates different devices for selection in a text- editing environment. The devices compared are: a mouse, a velocity-controlled isometric joystick, a group of step keys, and a group of text keys. Both the step keys and the text keys are cursor control keys. The step keys move the cursor up, down, left, right, or to the top of the upper left corner of the display, while the text keys move the cursor in units of paragraph, line, word, and character. Results from the study show the mouse to be the fastest and the most accurate device, followed by the joystick, the text keys, and the step keys. On the whole, the closed-loop feedback devices (the mouse and the joystick) are found to be better than the open-loop feedback devices (the step keys and the text keys) for selection. The experiment was extremely well conducted and the tasks the subjects performed were well monitored and described. One can generalize the device ratings found in this experiment to a non-text editing oriented environment.

CARD80 Card, S., T. Moran and A. Newell, "The Keystroke-Level Model for User Performance Time with Interactive Systems," Communications of the ACM 23, 7, (July 1980), 396-410.

CARU77 Caruthers, L., J. van der Bos and A. van Dam, "A Device-Independent General Purpose Graphic System for Stand-Alone and Satellite Graphics," Proceedings of SIGGRAPH '77, published in Computer Graphics 11, 2 (Summer 1977), 112-119.

CHAM70 Chambers, J.B. and H.C. Stockbridge, "Comparison of Indicator Components and Push-Button Recommendation," Ergonomics 3, 4 (1970), 401-420.

CHAP59 Chapanis, A., "Research Techniques in Human Engineering," Johns Hopkins Press (1959), 310 pp.

CHAP65 Chapanis, A., "Man-Machine Engineering," Wadsworth, Belmont, Ca. (1965).

CHAP72 Chapanis, A., "Design of Controls," Chapter 8 in [VANC72], pp. 345-380.

CHER76 Cheriton, D.R., "Man-Machine Interface Design for Timesharing Systems," Proceedings ACM 1976 Conference, pp 362-380.

This paper presents a design approach and design criteria for the man-machine interface in timesharing systems. A conceptual view of timesharing systems is outlined, focusing on the interface between the user and the capabilities of the system. We consider user needs and requirements for this interface and suggest design guidelines and approaches to meet these needs. Finally, we propose a model on which design and design standardization might be based and briefly sketch a design methodology.

CHRI75 Christ, R.E., "Review and Analysis of Color Coding, Research for Visual Displays", Human Factors 17, 6 (1975), 542-570.

The experimental literature on the effects of color on visual search and identification performance was reviewed. Forty-two studies published between 1952 and 1973 were located that gave results which could be used to determine the effectiveness of color codes relative to various types of achromatic codes. Quantitative analyses of these results indicated that color may be a very effective performance factor under some conditions, but that it can be detrimental under others. Tentative conclusions about the nature of these conditions were derived from the results. A guide for design decisions and an indication of knowledge gaps are also provided.

COFF61 Coffee, J.L., "A Comparison of vertical and horizontal arrangements of alpha-numerical materials", Human Factors 3 (1961), 93-98.

CONR66 Conrad, R., "Short-term Memory Factor in the Design Data-Entry Keyboard," Journal of Applied Psychology 50, (1966), 353-356.

An experiment on immediate recall of 8-digit sequence was carried out. Mode of recall was via a data-entry keyboard. Two keyboard layouts were used, 1 of high, 1 of low compatibility. The low-capatibility keyboard required more time for entry and gave more errors. These extra errors were identified as being primarily memory rather than aiming errors. The results were discussed in terms of an interface between short-term memory and S-R compatibility; they are held to support a memory model involving a limited-capacity channel and a practical design conclusion is suggested.

CROP68 Cropper, A. and S. Evans, "Ergonomics and Computer Display Design", The Computer Bulletin 12, 3 (July 1968), 94-98.

DEGR70 DeGreene, K.B., Ed., Systems Psychology, New York: McGraw-Hill (1970), ch. 10.

DEVO67 Devoe, D., "Alternatives to Handprinting in the Manual Entry of Data," IEEE Trans. on Human Factors in Electronics HFE-8 1 (January 1967), 21-32.

DRUR78 Drury C.G. and M.R. Clement, "Effect of Area, Density and Number of Background Characters on Visual-Search," Human Factors 20, 5 (1978), 369-384.

In a search task, area of search field, density of background characters, and number of background characters are not independent. Many authors have found increases in search times with each of these factors but have not adequately controlled all three together. In this experiment, eight subjects searched a set of search fields covering combinations of all three variables. Search time was found to depend most heavily on number of background characters, but there were significant effects due to the other two variables. For a constant number of background characters, search time decreases as density increases. Direct visual lobe measurements confirmed these findings, which could have importance in visual inspection tasks.

DUNN80 DUNN, R.M., "A Philosophical Prelude to Methodology of Interaction," Methodology of Interaction, North-Holland Publishing Company (May 1979), 183-188.

EARL65 Earl, W.K. and J.D. Goff, "Comparison of Two Data Entry Methods," Perceptual and Motor Skills, 20 (1965), 369-384.

This experiment compares the efficiency and accuracy of several selection techniques. In each case, three commonly used words to be entered are shown to the subjects, who enter the words in one of three ways:

1) Picking with a light pen from a menu. The desired words are guaranteed to be on the menu.

2) Picking from the menu, but with no guarantee that the words are on the menu. If the words are not found, the subject types them in.

3) Typing in all three words.

The results suggest that menu selection using a light pen is a faster and more accurate input technique for data selection than the other two techniques evaluated. The second technique, which required the use of two devices, is significantly slower.

ENGE73 Engelbart, D.C., "Design Considerations for Knowledge Workshop Terminals," AFIPS Conference Proceedings 42 (1973), 221-227.

ENGE75 Engel, S.E. and R. Granda, Guidelines for Manual Display Interfaces, IBM Technical Report, TR00 2720 (1975).

This report documents a set of human factors guidelines relating to the interface between a user of an interactive computing system and a display terminal connected to the system. Though intended primarily for the use of developers of software for an interactive system, many of the guidelines should be of interest to hardware developers. Areas covered include display frame layout, frame content, command languages, error prevention and recovery, response times, and behavioral principles.

ENGL67 English, W.K., D.C. Engelbart and M.L. Berman, "Display-Selection Techniques for Text Manipulation," IEEE Trans. on Human Factors in Electronics HFE-8, 1 (March 1967), 5-15.

The purpose of this experiment is to compare the performance of five selection devices. The first is the light pen, the remaining four, which are locators used to move a cursor to a target, are the mouse, the Grafacon (a now obsolete tablet), the knee control, and the joystick. The experimental results indicate that for the experienced user the mouse is by far the fastest and the least error-prone selection device, while for the inexperienced users, the knee control and the light pen are marginally faster than the mouse. For all users, the mouse is more accurate, with error rates typically half of those for other devices. At the other extreme, the joystick used as either an absolute or a controlled locator fared the poorest both in speed and accuracy. In spite of a few hardware and software problems which might have degraded the performance of the light pen and the joystick, the experiment was well coordinated and the procedures clearly described.

FIEL78 Fields, A.F., R.E. Maisano and C.F. Marshall, A Comparative Analysis of Methods for Tactical Data Inputting, Battlefield Information Systems Technical Area (September 1978), U.S. Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue, Alexandria, Va.

This research evaluates four methods of entering data in terms of speed, accuracy, and ease of learning. The data, taken from written intelligence reports, is in part numeric and in part words selected from a predefined set of terms. The different input techniques studied are:

1) Typing numeric codes, each corresponding to a term, of the entries into a displayed form (Label Type-In).

2) Typing as in 1, but with error correction attempted by the computer (Label Type-In with error correction).

3) Menu selection -- selecting the desired term from a list of legal terms using a track ball.

4) Typing only sufficient digits or characters to uniquely identify a term, using either the appropriate numeric code or the term itself. The computer automatically completes

the entry (Label Type-In with autocompletion).

Menu selection with a track ball was the most accurate input technique, and ranked second in speed performance, only slightly slower than Label Type-In. The results suggest that menu selection with occasional typing is a viable interaction technique for text inputting, if the set of data is fixed and small.

FLAN76 Flanagan, J. L., "Computers that Talk and Listen: Man-Machine Communiction by Voice," Proceedings of the IEEE 64, 4 (April 1976), 405-415.

Computer techniques now emerging in the laboratory promise new capabilities for voice communication between man and machine. Three modes of interaction are of special interest: computer voice readout of stored information, automatic verification o a caller's identity by means of his voice signal and automatic recognition of spoken commands. Applications extend to: voice-directed installation of telephone equipment, authentication by voice of a credit customer or of an individual requesting readout of privileged information, and voice-controlled services such as repertory dialing or automatic booking of travel reservations.

FITT54 Fitts, P.M., "The Information Capacity of the Human Motor System in Controlling Amplitude of Movement," Journal of Experimental Psychology 67 (1954), 381-391.

FITT64 Fitts, P.M. and J.R. Peterson, "Information Capacity of Discrete Motor Responses," Journal of Experimental Psychology 67 (1964), 103-112.

FITT66 Fitts, P.M. and B. Radford, "Information Capacity of Discrete Motor Responses Under Different Cognitive Sets," Journal of Experimental Psychology 71 (1966), 475-482.

FOLE74 Foley, J.D. and V.L. Wallace, "The Art of Graphic Man-Machine Conversation," Proc. of the IEEE (April 1974), 462-471.

FOLE80 Foley, J.D., "The Structure of Interactive Command in Methodology of Interaction," 409 p., North-Holland Publishing Company (May 1979), 227-234.

FOLE81 Foley, J. and A. van Dam, Fundamentals of Interactive Computer Graphics, Addison - WesleY (1981).

GAIN75 Gaines, B. and P. Facey, "Some Experiences in Interactive System Development and Application," Proceedings of the IEEE 63, 6 (June 1975).

GALL66 Gallo, J. and J. Levine, Human Factors in the Design of an Observer's Keyset, U.S. Navy Electronics Laboratory, San Diego, California (October 1966).

On a chord keyboard, subjects enter the desired command by depressing the appropriate patterns of keys. As a result of a pilot study done before the experiments conducted in this research, it was found that command entry on a chord keyboard in the manual mode of command-entry is much slower and more error-prone than in the automatic mode. In the study subjects entered one of the 26 alternatives coded in five-bit patterns by pressing the appropriate keys to automatically enter the command; in the manual mode, only by striking the entry bar, which is similar to a space bar, would the subject enter the message. Even though no experimental results were given, the authors strongly stated that the use of the entry bar greatly increased the error rates and sharply decreased the input rates.

GOOD75 Goodwin, N.C., "Cursor Positioning on an Electronic Display Using Lightpen, Lightgun, or Keyboard for Three Basic Tasks," Human Factors 17, 3 (1975), 289-295.

This experiment compares the performance of the light pen, the lightgun, (a variant of the light pen using a pistol grip) and step keys with cursor match for selection on an alphanumeric display. The only measurement considered was the time taken to move the cursor to a target character on the display screen, and then to type a replacement character on the keyboard. Experimental results showed no significant difference between the light pen and the light gun, but both devices were faster than the cursor positioning keys. In the extreme case, in which the subject moves the cursor large distances over the display, step keys were found to be five times slower. However, this result is partly because the step keys force cursor movement to be line-by-line, rather than in arbitrary up-down-left-right direction.

GSPC79 "General Methodology and the Proposed Core System," (Report of the Graphics Standards Planning Committee) Computer Graphics, 13, 3 (August 1979), 179 pp.

HANS71 Hansen, W. J., "User Engineering Principles for Interactive Systems," Fall Joint Computer Conference, (1971), 523-532.

HERO78 Herot, C. and G. Weinzapfel, One - Point Touch Input of Vector Information for Computer Displays," Proceedings 1978 SIGGRAPH Conference, published as Computer Graphics 12, 3 (August 1978), 210-216

HOLM74 Holmgren, J.E., "Effect of a Visual Indicator on Rate of Visual Search-Evidence for Processing Control," Perception and Psychophysics 15, 3 (1974), 544-550.

HORN67 Hornbuckle, G.D., "The Computer Graphics/User Interface," IEEE Trans. HFE-8, 1 (March 1967), 17-

HUNS70 Hunstad, A. and B.M Brown, "An Evaluation of Certain Interactive Input Devices Associated with Computer Driven Displays," Agard

Conference Proceedings on Data Handling Devices (1970), 8.

HUTC70 Hutchinson, A., "Labanotation", Theatre Arts Books, New York (1970).

IRVI76 Irving, G.W., J.J. Horineek, D.H. Walsch and P.Y. Chan, ODA Pilot Study II: Selection of an Interactive Graphics Control Device for Continuous Subjective Functions Applications, (Report No. 215-2), Santa Monica, California: Integrated Sciences Corp (April 1976).

The study evaluates three locator techniques -- light pen with tracking cross, trackball, and joystick, to move a cursor to a random position and then do free hand sketching of an equilateral triangle and a circle. The performance measures were: the straightness of the sides of the triangle, the closeness the drawn triangle to an equilateral triagle, and the standard deviation of sample points on the drawn circle from the centroid of the circle. The trackball was preferred over the others for the tasks described. Because the evaluation criteria used were not very realistic and because the number of subjects and replications taken were small, the results require further validation.

JENK49 Jenkins, W.L. and M.B. Connor, "Some Design Factors in Making Settings on a Linear Scale", J. of Appl. Psychology, 33, (1949), p. 395

JENK50 Jenkins, W.L., L.O. Maas and D. Rigler, "Influence of Friction in Making Settings on a Linear Scale", J. of Appl. Psychology, 34, (1950), p. 434.

JENK54 Jenkins, W.L. and A.C. Karr, "The Use of a Joystick in Making Settings on a Simulated Scope Face", J. of Appl. Psychology, 38, (1954), p. 457.

JOHN77 Johnson, J.K., "Touching Data," Datamation 23, 1 (January 1977), 70-72.

KLAP75 Klapp, S.T., " Feedback Motor Programming in the Control of Aimed Movements," Journal of Experimental Psychology: Human Perception & Performance 104 (1,2) (May 1975), 147-153.

KENN75 Kennedy. T.C., "Some Behavior Factors Affecting the Training of Naive Users of an Interactive Computer System," International Journal of Man-Machine Studies 7 (1975), 817-834.

KENN75 Kennedy, T.C., "Design of Interactive Procedures for Man-Machine Communication," International Journal of Man-Machine Studies 7 (1975), 233-247.

KLEM71 Klemmer, E.T., "Keyboard Entry," Applied Ergonomics 2, 1 (1971), 2-6.

Many recent studies of keyboard entry are summarized with particular emphasis on performance data and fundamental questions about the design of keyboards. The role of auditory and visual feedback and physiological measurements are reviewed. Typical speed and error rates are given for several types of situations and operators. Other methods of data entry are consdered, as are source documents, ordering of keys, keyboard interlocks, and chord keyboards. These data should be of interest to anyone concerned with the design and use of keyboards or other data entry devices.

KOLE79 Kolers, P.A., M.E. Wrolstad and H. Bouma (eds.), "Processing of Visible Language," Vol. 1, Plenum Press, N.Y. (1979), 537 pp.

KROE72 Kroemer, K.H., "Human Engineering the Keyboard", Human Factors 14 1 (1972), 51-63.

The standard typewriter keyboard serves as a model for keyboards of teletypewriters, desk calculators, consoles, computer keysets, cash registers, etc. This man-machine interface should be designed to allow high frequency, error free operation with the least possible strain on the operator. This paper discusses several feasible biomechanical improvements of the kyboard. Some experimental findings are described which support the following design concepts: (1) the keys should be arranged in a "hand-configured" grouping to simplify the motion patterns of the fingers; (2) the keyboard sections allotted to each hand should be physically separated to facilitae the positioning of the fingers; and (3) the keyboard sections allotted to each hand should be declined laterally to reduce postural muscular strain of the operator.

LACH79 Lachman, R., J.L. Lachman and E.C. Butterfield, "Cognitive Psychology and Information Processing: An Introduction," Lawrence Erlbaum Associates, Hillsdale, N.J. (1979), 573 pp.

LINS77 Linsay, P. and D. Norman, Human Information Processing, second edition, Academic Press (1977).

MCCO76 McCormick, E.J., "Human Factors in Engineering and Design," Fourth edition, McGraw-Hill, New York, 491 pp.

MCMI75 McMichael, E. and S. McCarthy, "Visual Search through Words and Nonwords in Horizontal and Vertical Orientations," Perceptual and Motor Skills 41, 3 (1975), 740-742.

MEHR72 Mehr, M.H. and E. Mehr, "Manual Digital Positioning in 2 Axes: A Comparison of Joystick and Track Ball Controls," Proceedings of the 16th Annual Meeting of The Human Factors Society, (October 1972).

MEIS71 Meister, D., "Human Factors: Theory and Practice," Wiley-Interscience (1971), 415 pp.

MEIS76 Meister, D., "Behavioral Foundations of System Development," Wiley-Interscience (1976), 376 pp.

MICH79 Michon, J.A., E.G. Eijkman, G.J de Klerk, and F.W. Len, Handbook of Psychonomics Vol. I and II. North-Holland, Amsterdam (1979).

MILL73 Miller, L.A., and J.C. Thomas, "Behavioral Issues in the User of Interactive Systems," International Journal of Man-Machine Studies 9, 56 (September 1977), 509-536.

MORA78 Moran, T.P., "Introduction the Command Language Grammar: A Representation for the User Interface of Interactive Computer Systems," Xerox Palo Alto Research Center, Report SSL-78-3 (1978).

MORA80 Moran, T.P. and S.K. Card, "The Keystroke-Level Model for User Performance Time with Interactive Systems," Communications of the ACM 23, 7 (July 1980), 396-410.

MORR68 MOrrill, C.S., N.C. Goodwin and S.L. Smith, "User Input Mode and Computer-Aided Instruction," Human Factors 10, 3 (1968), 225-232.

NEIS67 Neisser, Ulric, "Cognitive Psychology," Prentice-Hall (1967), 351 pp.

NEWM68 Newman, W.M., "A Graphical Technique for Numerical Input," Computing Journal 11 (May 1968), 63-64.

NEWM79 Newman, W.M. and R.F. Sproull, Principles of Interactive Computer Graphics, Mc-Graw-Hill, New York (1979).

NILS79 Nilsson, L.G. (ed.), Perspectives on Memory Research: Essays in Honor of Uppsala Universities' 500th Anniversary," Lawrence Erlbaum Associates, Hillsdale, N.J. (1979), 400 pp.

OHLS78 Ohlson, M., "System Design Considerations for Graphics Input Device," Computer 11, 11 (November 1979), 9-18.

PETE77 Peterson, J.L., "Petri Nets", Computing Surveys, 9, 3 (1977).

RAMS78 Ramsey, H.R., M.E. Atwood and P.J. Kirshbaum, "A Critically Annotated Bibliography of the Literature of Human Factors in Computer Systems," Technical Report SAI-78-070-DEN, Science Applications, Inc., (May 31, 1978).

RAMS79 Ramsey, H.R. and M.E. Atwood, "Human Factors in Computer Systems: A Review of the Literature," Technical Report SAI-79-111-DEN, Science Applications, Inc. (Sept. 21, 1979), 169 pp. Availble from NTIS as AD-A075-679.

REYN77 Reynolds, A.G. and P.W. Flagg, "Cognitive Psychology," Winthrop Publishers, Cambridge, Mass., 457 pp.

RICH75 Richard, E.G., "Development of Display Guidelines for Human User - An Experimental Approach," Human Factors and Graphics, International Business Machines Corporation, New York (1975).

RITC75 Richtie, G.J. and J.A. Turner, "Input Devices for Interactive Graphics," International Journal of Man-Machine Studies 7 (1975), 639-660.

ROOT67 Root, R.T. and R. Sadacca, "Man-computer Communication Techniques: Two Experiments," Human Factors 9 (1967), 521-528.

Two experimental studies are reported that were intended to evaluate alternative man-computer communication techniques within the context of a computer-based image interpretation facility. The first experiment, comparing five different data entry procedures, indicated that, although a procedure requiring the interpreter to enter report data directly using a teletype keyboard resulted in the shortest overall throughput time, a procedure involving message composition by the image interpreter with subsequent transcription by a communicator minimizes the time spent by the interpreter in report generation and maximizes the time available for the detection and identification of targets on aerial imagery. The second experiment evaluating alternative word form-data entry format combinations, showed no differences among the six combinations studied.

ROUS75 Rouse, W.B., "Design of Man-Computer Interfaces for On-Line Interactive Systems," Proc. IEEE 63, 6 (June 1975), 847-857.

SEIB72 Seibel, R., "Data Entry Devices and Procedures," in H.P. Van Cott & R.G. Kinkade (Eds.), Human Engineering Guide to Equipment Design (Revised Ed.), Washngton, D.C.: U.S. Government Printing Office (1972), 311-344.

SHAC70 Shackel, B. and P. Shipley, Man-Computer Interaction: A Review of Ergonomics Literature and Related Research (Rpt. no. DMP-3473), Hayes, Middlesex, England: EMI Electronics Ltd. (February 1970). Hayes, Middlesex, England: EMI Electronics Ltd. (February 1970).

SHER67 Sheridan, T.B. (ed.), IEEE Trans. on Human Factors Electronics, Special Issue on Man-Computer Input-Output Techniques HFE-8, (March 1967).

SHER74 Sheridan, T.B. and W.R. Ferrell, "Man-Machine Systems. Information, Control, and Decision Models of Human Performance," MIT Press (1974), 452 pp.

STEW76 Stewart, T.F.M., "Displays and the Software Interface," Applied Ergonomics 7, 3 (1976), 137-146.

TEIC74 Teichner, W.H. and M.J. Krebs, "Visual Search for Simple Targets," Psychological Bulletin 81, 1 (1974), 15-28.

THOM71 Thompson, D.A., "Interface Design for an Interactive Information Retrieval System: a Literature Survey and a Research System Description," Journal of the American Society for Information Science 22 (1971), 361-373.

TREU75 Treu, S., "Interactive Command Language Design Based on Required Mental Work," International Journal of Man-Machine Studies 7, 1 (1975), 135-149.

UBER68 Uber, G.T., P.E. Williams, B.L. Hisey and R.G. Siekert, "The Organization and Formatting of Hierarchical Displays for the On-Line Input of Data," AFIPS Conference Proceedings 33 (1968), 219-226.

UNDE78 Underwood, G. (ed.), Strategies of Information Processing, Academic Press (1978), London, 455 pp.

VANC72 VanCott, H.P. and R.G. Kinkade, "Human Engineering Guide to Equipment Design, revised edition, 752 p., U.S. Government Printing Office, stock number 008-051-00050-0, catalog number D4.10:EN3.

VART65 Vartabedian, A. G., "Human Factors Evaluation of Several Cursor Forms for Use on Alphanumeric CRT Displays," IEEE Trans. on Human Factors in Electronics HFE-6 (September 1965), 74-83.

VART70 Vartabedian, A.G., "Human Factors Evaluation of Several Cursor Displays," IEEE Trans. on Man-Machine systems MMS-11, 2 (1970), 132-137.

VAUG76 Vaughan, J., "Scanning Strategies in Visual-Search," Bulletin of the Psychonomic Society 8, 4 (1976), 262-263.

WALL76 Wallace, V.L., "The Semantics of Graphic Input Devices," Proc. of the SIGGRAPH/SIGPLAN Symmposium on Graphics Languages (April 1976), 61-65.

WALL77 Wallace, V.L., "Conversational Ergonomics," Workshop on User Oriented Design of Interactive Graphics Systems, ACM, Pittsburgh, (October 1976).

WOOD64 Woodson, W.E. and D.W. Conover, "Human Engineering Guide for Equipment Designers," Second ed., Univ. of Cal. Press (1964).